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Process Control Manual for Aerobic Biological Wastewater Treatment Facilities

James M. Montgomery, Inc, Walnut Creek, Calif

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PROCESS CONTROL MANUAL FOR

AEROBIC BIOLOGICAL WASTEWATER TREATMENT FACILITIES

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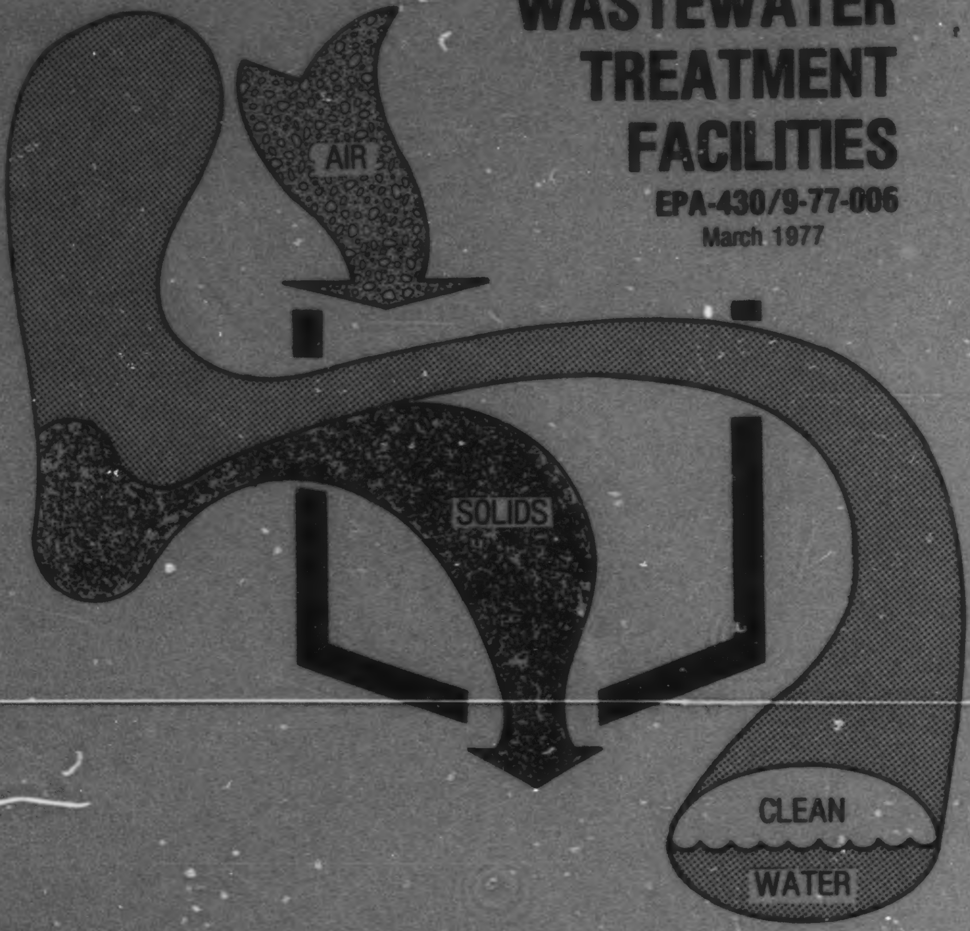

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This document provides an on-the-job reference for operators of activated sludge and trickling filter wastewater treatment plants. It will also assist operators in establishing process control techniques and optimizing the performance of these two aerobic biological treatment systems.

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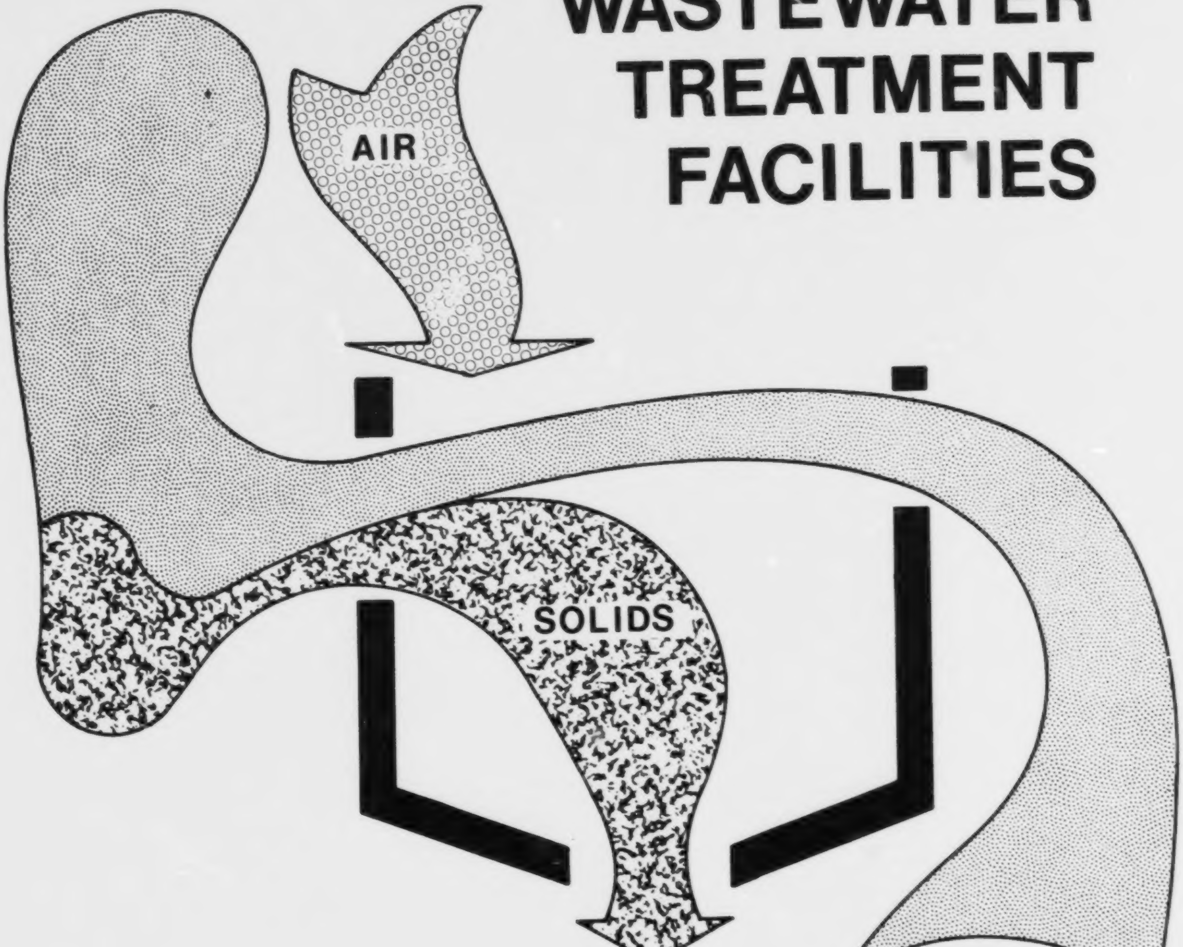
AEROBIC BIOLOGICAL WASTEWATER TREATMENT FACILITIES



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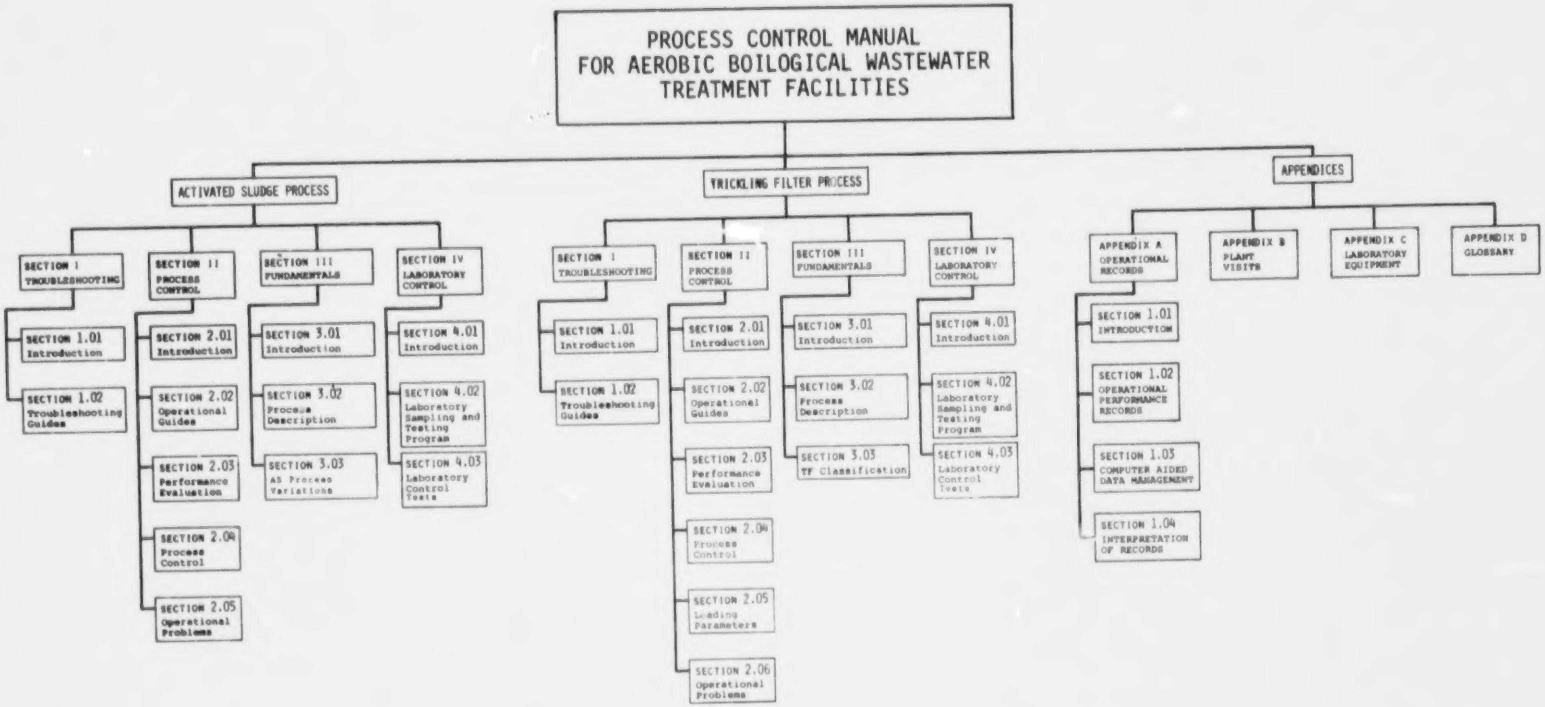
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SECTION 1.01 Introduction
SECTION 1.02 Troubleshooting Guides
SECTION II PROCESS CONTROL
SECTION 2.01 Introduction
SECTION 2.02 Operational Guides
SECTION 2.03 Performance Evaluation
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APPENDIX C LABORATORY EQUIPMENT
APPENDIX D GLOSSARY

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Mr. William Loftin	Livermore, California
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INTRODUCTION

A. PURPOSE AND INTENT

The purpose of this manual is to provide an on-the-job reference for operators of activated sludge and trickling filter wastewater treatment plants. It is intended to assist operators in establishing process control techniques and in optimizing the performance of these two aerobic biological treatment systems. Other aerobic biological systems such as aerated lagoons, rotating biodiscs and oxidation ponds are not included in this manual.

Aerobic biological treatment facilities and the conditions under which they operate can vary considerably. Although treatment plants may be designed alike, they may not necessarily perform alike. In the past, many control strategies have been the result of trial and error tests performed by operators and engineers.

Development of this manual consisted of visiting several operators at their treatment plants throughout the United States. Their practical experiences and knowledge in plant operations and process control have been incorporated in the manual. In addition, extensive use was made of the literature contributed over the years by those individuals, agencies, and institutes seeking to advance and explain the state-of-the-art of operating aerobic biological wastewater treatment facilities.

The overall objective of this manual is to aid the operator in determining what process control and operational measures may be most effective in optimizing the performance of his particular treatment plant. The manual should also serve as a basis from which the operator may develop new ideas for process control and better understand the various measures by relating his own experiences to the material presented. For this reason, theoretical material has been limited to that required for basic understanding of aerobic biological treatment.

B. MANUAL ORGANIZATION

The manual is presented in three major divisions:

- The Activated Sludge Process
- The Trickling Filter Process
- Appendices

The Activated Sludge and Trickling Filter Process divisions are each divided into the following sections:

Section I - Troubleshooting
Section II - Process Control
Section III - Fundamentals
Section IV - Laboratory Control

These sections emphasize the fundamentals of operating and controlling aerobic biological treatment processes. Each of the sections are presented in sufficient detail to allow the reader to use them independently. References have been appended to each section for those who wish to gain further insight to the topics covered in the manual. These references were selected because of their clarity and value to an operator as an information source.

INTRODUCTION

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Inside front cover.

Key words.

Included on the inside front cover is a quick reference index to the major topics in each division section of the manual. After finding the section you desire, go to the Table of Contents for the subsection of interest. Once you are in the appropriate subsection, thumb down the left hand margin of the text until you find the key words which best fit your interest. Key words are presented in the manner shown to the left of this paragraph.

Inside back cover.

The inside back cover presents a Metric Reference for those unit expressions which are commonly used for process control parameters. This reference may be used for converting English and Metric unit expressions.

Abbreviations.

Abbreviations have been kept to a minimum in the manual. Only those which are commonly used are included in the text.

C. USE OF THE MANUAL

Are you familiar with aerobic treatment?

This manual assumes that the reader is familiar with the activated sludge and trickling filter processes as well as their various modes of operation. For those who are not quite familiar enough, you are encouraged to study Section III, "FUNDAMENTALS", in each process division.

As stated earlier, each process division is broken down into four sections. These sections may be used independently or systematically.

SECTION I

TROUBLESHOOTING — If you have a problem, go to the troubleshooting guide which best describes your situation. Follow the guidance as outlined. If you still have problems or desire more information on the guidance provided, use the reference indicated in the last column on the troubleshooting guide. This reference will lead you into the text of the manual to provide you with more insight, as well as additional references to get more information. Your next best alternative would be to seek outside help.

SECTION II

PROCESS CONTROL — This section presents the various strategies commonly used for controlling the activated sludge and trickling filter processes. Routine operational procedures as well as process loadings, evaluations, and common problems are presented here. Step-by-step examples of calculating, interpreting and applying control tests to process control parameters are also presented.

SECTION III

FUNDAMENTALS — This section is where it all begins. Without a sound background in understanding the concepts of aerobic biological treatment, a successful process control and operational program is difficult to achieve. As a result, the quality of plant effluent suffers the consequences. Therefore, be familiar with the fundamentals and the references that show you where to get more information.

SECTION IV

LABORATORY CONTROL — This section is a must. If you want to know why, read it and follow its guidance because it will help you establish and implement a successful sampling, testing, and monitoring program for your aerobic treatment facility.

Four appendices are provided to supplement the manual.

APPENDIX A — Includes work sheets which may be removed and duplicated for actual use. It also provides information to develop an operational records system.

APPENDIX B — Presents flow diagrams, operational data, and summary descriptions of those treatment plants which were visited during development of the manual. Check them over to see how you compare.

APPENDIX C — Is a suggested list of laboratory equipment, supplies and chemicals needed to perform process control tests discussed in the manual.

APPENDIX D — Is a glossary which defines the important terminology commonly used in discussing aerobic biological treatment.

Operators' responsibility to achieve best process control and operation.

During the plant visits, four characteristics were observed of those treatment plants producing a good-quality secondary effluent.

1. Practice of day-to-day process control and operational control procedures.
2. Special effort is made for training and upgrading of plant personnel.
3. Industrial waste discharge ordinances are actively enforced.
4. Process control and operational data is used in direct application to plant operations.

HOW DO YOU COMPARE?

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1.01 INTRODUCTION

Select the measure with least adverse effect.

This section of the manual presents troubleshooting procedures for solving common operating problems experienced in the activated sludge process. With each problem, or observation, a list is included for the probable causes, checks to determine the cause, and the suggested corrective measures. You, the operator, must determine and select one or more of the corrective measures that will restore the process to full efficiency with the least adverse effect on the final effluent quality. In order to evaluate the problem and select the best corrective measure, you must be thoroughly familiar with your activated sludge process and how it fits into the overall treatment plant operation. In addition, you must be familiar with the influent wastewater characteristics, plant flow rates and patterns, design and actual loading parameters, performance of the overall plant and individual processes, and current maintenance procedures. For those operators who are not familiar with the activated sludge process, refer to Section III, "FUNDAMENTALS" before attempting to use the troubleshooting guides.

Know the process.

1.02 TROUBLESHOOTING GUIDES

There are seven problems presented that frequently occur in operating the activated sludge process. These problems are listed below and are referenced to the troubleshooting guides which begin on the following pages.

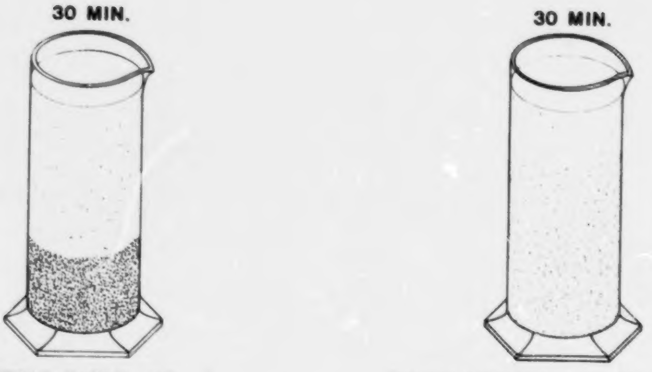
Common problems with activated sludge processes.

Note that the problems are categorized between the aeration tank and secondary clarifier tank. The troubleshooting guides presented for the secondary clarifier tank are associated with the activated sludge characteristics and quality, as can be observed when performing the sludge settleability test. The operator must realize that all observations made during the settleability test are not necessarily indicative of conditions occurring in the secondary clarifier tank. In all of the guides presented, the probable causes given for the observation should be looked at concurrently because many times one problem may be the result of several causes.

INDEX TO TROUBLESHOOTING GUIDES

Troubleshooting Guide No.	Problem Indicator
Aeration Tank	
1	Aeration System Problems
2	Foaming Problems
Secondary Clarifier	
3	Solids Washout/Billowing Solids
4	Bulking Sludge
5	Sludge Clumping
6	Cloudy Secondary Effluent
7	Ashing, Pinpoint/Straggler Floc

Figure I-1 presents a pictorial index of typical settleability test results. This index may be used in comparing actual test results for quick reference to the troubleshooting guides.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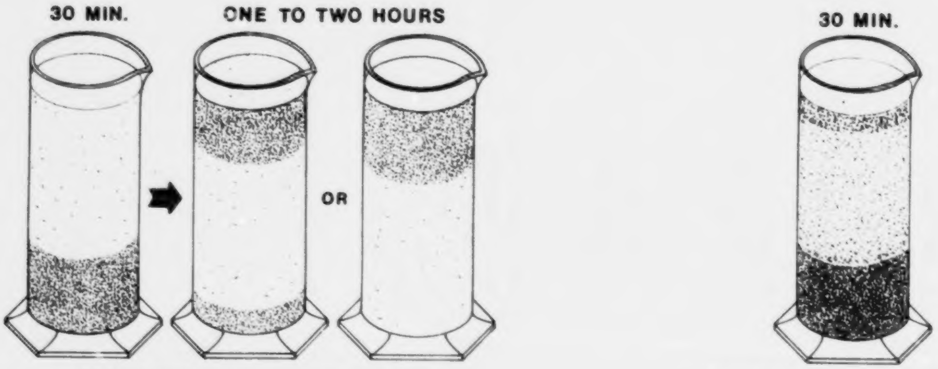
TROUBLESHOOTING GUIDE NO. 3
GOOD SETTLING

TROUBLESHOOTING GUIDE NO. 4
POOR SETTLING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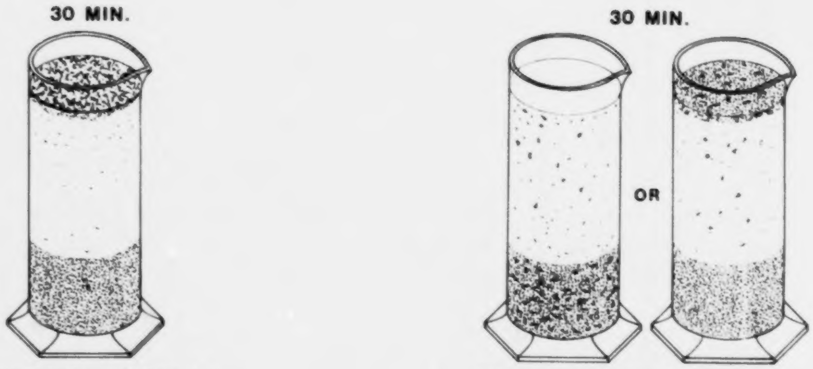
TROUBLESHOOTING GUIDE NO. 5
DENITRIFICATION

TROUBLESHOOTING GUIDE NO. 6
CLOUDY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OR

TROUBLESHOOTING GUIDE NO. 7
ASH ON SURFACE

TROUBLESHOOTING GUIDE NO. 7
PIN POINT FLOC & STRAGGLERS

SETTLING TEST OBSERVATIONS

FIGURE I-1

ACTIVATED SLUDGE PROCESS
AERATION TANK

TROUBLE SHOOTING GUIDE NO. 1 - AERATION SYSTEM PROBLEMS

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Boiling action, violent turblance throughout aeration tank surface. Large air bubbles, 1/2" or greater apparent.	A. Overaeration resulting in high D.O. and/or floc shearing.	1. Generally, D.O. should be in range of 1.0 to 3.0 mg/l throughout tanks.	1) Reduce air SCFM rate to maintain D.O. in proper range.	pg II-24 & II-72
2. Uneven surface aeration pattern. Dead spots or inadequate mixing in some areas of tank.	A. Plugged diffusers.	1. Check maintenance records for last cleaning of diffusers.	1) If diffusers have not been cleaned in the last 12 months, do so.	pg II-72
		2. Spot check diffusers in tank for plugging.	2) If several are plugged, clean all diffusers in tank.	pg II-72
	B. Underaeration resulting in low D.O. and/or septic odors.	1. Check D.O., should be in range of 1.0 to 3.0 mg/l throughout tank.	1) Increase air SCFM rate to maintain D.O. in proper range.	pg II-24
		2. Check for adequate mixing in aeration tank.	2) Calculate SCFM of air per linear foot of diffuser header pipe. Minimum requirement is 3 SCFM/linear ft. Adjust air SCFM rate as necessary to maintain adequate D.O. and mixing.	pg II-9
		3. Check RAS rates and sludge blanket depth in clarifier.	3) Adjust RAS rate to maintain sludge blanket depth of 1 to 3 feet in clarifier.	pg II-29

ACTIVATED SLUDGE PROCESS
AERATION TANK

TROUBLE SHOOTING GUIDE NO. 1 — AERATION SYSTEM PROBLEMS (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
3. Excessive air rates being used with no apparent change in organic or hydraulic loading. Difficult to maintain adequate D.O. level.	A. Leaks in aeration system piping.	1. Check air pipe and joint connection; listen for air leakage or soap test flanges and watch for bubbling caused by air leaking.	1) Tighten flange bolts and/or replace flange gaskets.	
	B. Plugged diffusers. Air discharging from diffuser header blow-off pipes causing local boiling to occur on surface near diffuser header pipe.	1. Check maintenance record for last cleaning of diffusers.	1) If diffusers have not been cleaned in last 12 months, do so.	pg II-72
		2. Spot check diffusers in tank for plugging.	2) If several are plugged, clean all diffusers in tank.	pg II-72
	C. Insufficient or inadequate oxygen transfer.	1. Check aeration system performance.	1) Replace with more effective diffusers or mechanical aerators.	pg II-9 & III-4
		a. Diffused aeration system should provide between 800 to 1500 cu. ft. air per pound BOD removed. b. Mechanical aeration system should provide between 1 to 1.2 pounds oxygen per pound BOD removed.	2) Add more diffusers or mechanical aerators.	pg II-9 & III-4
	D. High organic loadings (BOD, COD, Suspended matter) from in-plant side stream flows.	1. Check to see if organic loading from side stream flows contributes significantly to overall process loading.	1) If loadings are greater than 25%, optimize operational performance or upgrading of other inplant processes will be required.	pg II-9

ACTIVATED SLUDGE PROCESS
AERATION TANK

TROUBLESHOOTING GUIDE NO. 2 — FOAMING PROBLEMS

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. White, thick, billowing or sudsy foam on aeration tank surface.	A. Overloaded aeration tank (low MLSS) due to process start-up. Do not be alarmed, this problem usually occurs during process start-up.	1. Check aeration tank BOD loading (1bs/day) and lbs MLVSS in aeration tank. Calculate F/M ratio to determine lbs/day MLVSS inventory for current BOD loading.	1) After calculating the F/M and lbs MLVSS needed, you will find that the F/M ratio is high and the lbs MLVSS inventory is low. Therefore, do not waste sludge from the process or maintain the minimum WAS rate possible if wasting has already started.	pg II-75. II-12 & II-42
		2. Check secondary clarifier effluent for solids carryover. Effluent will look cloudy.	2) Maintain sufficient RAS rates to minimize solids carryover especially during peak flow periods.	pg II-29
		3. Check D.O. levels in aeration tank.	3) Try to maintain D.O. levels between 1.0 to 3.0 mg/l. Also be sure that adequate mixing is being provided in the aeration tank while attempting to maintain D.O. levels.	pg II-24
	B. Excessive sludge wasting from process causing overloaded aeration tank (Low MLSS).	1. Check and monitor for trend changes which occur in the following: a. Decrease in MLVSS mg/l. b. Decrease in MCRT, Gould Sludge Age. c. Increase in F/M ratio. d. D.O. levels maintained with less air rates. e. Increase in WAS rates.	1) Reduce WAS rate by not more than 10% per day until process approaches normal control parameters. 2) Increase RAS rate to minimize effluent solids carry-over from secondary clarifier. Maintain sludge blanket depth of 1 to 3 feet from clarifier floor.	pg II-36 pg II-29

ACTIVATED SLUDGE PROCESS
AERATION TANK

TROUBLESHOOTING GUIDE NO. 2 — FOAMING PROBLEMS (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
	C. Highly toxic waste, such as metals or bacteriocide, or colder wastewater temperatures, or severe temperature variations resulting in reduction of MLSS.	1. Take MLSS sample and test for metals and bacteriocide, and temperature.	1) Reestablish new culture of activated sludge. If possible, waste sludge from process without returning to other in-plant systems. Obtain seed sludge from other plant, if possible.	pg II-93 & II-94
		2. Monitor plant influent for significant variations in temperature.	2) Actively enforce Industrial Waste Ordinances.	pg II-94
	D. Hydraulic washout of solids from secondary clarifier.	1. Check hydraulic detention time in aeration tank and surface overflow rate in secondary clarifier.	1) Refer to Troubleshooting Guide No. 3, Observation 1.	pg II-23 & II-78
	E. Improper influent wastewater and/or RAS flow distribution causing foaming in one or more aeration tanks.	1. Check and monitor for significant differences in MLSS concentrations between multiple aeration tanks.	1) MLSS and RAS concentrations, and D.O.'s between multiple tanks should be reasonably consistent.	pg II-78 & IV-3
		2. Check and monitor primary effluent and /or RAS flow rates to each to aeration basin.	2) Modify distribution facilities as necessary to maintain equal influent wastewater and/or RAS flow rates to aeration basins.	pg II-78

ACTIVATED SLUDGE PROCESS
AERATION TANK

TROUBLESHOOTING GUIDE NO. 2 — FOAMING PROBLEMS (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
2. Shiny, dark-tan foam on aeration tank surface.	A. Aeration tank approaching underloaded (high MLSS) condition due to insufficient sludge wasting from the process.	1. Check and monitor for trend changes which occur in the following: a. Increase in MLVSS mg/ b. Increase in MCRT, Gould Sludge Age. c. Decrease in F/M ratio. d. D.O. levels maintained with increasing air rates. e. Decrease in WAS rates.	1) Increase WAS rate by not more than 10% per day until process approaches normal control parameters and a modest amount of light-tan foam is observed on aeration tank surface. 2) For additional checks and remedies refer to Troubleshooting Guide No. 5 and 6. 3) For multiple tank operation refer to Observation No. 1, Probable Cause "E".	pg II-76 & II-36
3. Thick, scummy dark-tan foam on aeration tank surface.	A. Aeration tank is critically underloaded (MLSS too high) due to improper WAS control program.	1. Check and monitor for trend changes which occur in the following: a. Increase in MLVSS mg/l. b. Increase in MCRT, Gould Sludge Age. c. Decrease in F/M ratio.	1) Increase WAS rate by not more than 10% per day until process approaches normal control parameters and a modest amount of light-tan foam is observed on aeration surface.	pg II-76 & II-36

ACTIVATED SLUDGE PROCESS
AERATION TANK

TROUBLESHOOTING GUIDE NO. 2 — FOAMING PROBLEMS (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
		d. D.O. levels maintained with increasing air rates. e. Decrease in WAS rates. f. Secondary effluent nitrate level above 1.0 mg/l. g. Increase in secondary effluent chlorine demand. h. Decrease in aeration tank effluent pH.	2) For additional checks and remedies refer to Troubleshooting Guide No. 5 and 7. 3) For multiple tank operation refer to Observation No. 1, Probable Cause "E" of this guide.	
4. Dark-brown, almost blackish sudsy foam on aeration tank surface. Mixed liquor color is very dark-brown to almost black. Detection of septic or sour odor from aeration tank.	A. Anaerobic conditions occurring in aeration tank.	1. Refer to Troubleshooting Guide No. 1, Observation No. 2 and 3.		

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 3 — SOLIDS WASHOUT/BILLOWING SOLIDS

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Localized clouds of homogenous sludge solids rising in certain areas of the clarifier. Mixed liquor in settleability test settles fairly well with a clear supernatant.	A. Equipment malfunction.	1. Refer to Troubleshooting Guide No. 1, Observations 1-A, 2-A, and 2-B.		
		2. Check the following equipment for abnormal operation. a. Calibration of flow meters. b. Plugged or partially plugged RAS or WAS pumps and transfer lines. c. Sludge collection mechanisms, such as broken or worn out flights, chains, sprockets, squeegees, plugged sludge withdrawal tubes.	2) Repair or replace abnormal operating equipment.	pg II-77
		3. Check sludge removal rate and sludge blanket depth in clarifier.	3) Adjust RAS rates and sludge collector mechanism speed to maintain sludge blanket depth at 1 to 3 feet from clarifier floor.	pg II-29

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 3 — SOLIDS WASHOUT/BILLOWING SOLIDS (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
	B. Air or gas entrapment in sludge floc or denitrification occurring.	1. Perform sludge settleability test and gently stir sludge when settling to see if bubbles are released.	1) If the process is not nitrifying, refer to Probable Cause A above, and Troubleshooting Guide No. 7, Observation 2.	pg II-90
		2. If bubbles are released, check nitrate mg/l in secondary effluent to see if the process is nitrifying.	2) If the process is nitrifying, refer to Troubleshooting Guide No. 5, Probable Cause A.	
	C. Temperature currents.	1. Perform temperature and D.O. profiles in clarifier.	1) If temperatures exceed 1 to 2 degrees between top and bottom of clarifier, use an additional aeration tank and clarifier if possible.	pg II-81
		2. Check inlet and outlet baffling for proper solids distribution in clarifier.	2) Modify or install additional baffling in clarifiers.	pg II-81
			3) Refer to Probable Cause A-1, and A-2 above.	
	D. Solids washout due to hydraulic overloading.	1. Check hydraulic detention time in aeration tank and clarifier, and surface overflow rate in clarifier.	1) If hydraulic loadings exceed design capability, use additional aeration tanks and clarifiers if possible.	pg II-78
			2) Reduce RAS rate to maintain high sludge blanket depth in clarifier.	pg II-29
			3) If possible, change process operation to sludge reaeration or contact stabilization mode.	pg III-15
			4) Refer to Probable Causes B-1, B-2, and C-2 above.	

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 3 — SOLIDS WASHOUT/BILLOWING SOLIDS (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
2. Localized clouds of fluffy homogenous sludge rising in certain areas of the clarifier. Mixed liquor in settleability test settles slowly, leaving stragglers in supernatant.	A. Overloaded aeration tank (low MLSS) resulting in a young, low density sludge.	1. Check and monitor trend changes which occur in the following: a. Decrease in MLVSS, mg/l. b. Decrease in MCRT, Gould Sludge Age. c. Increase in F/M ratio. d. Lower air SCFM rate to maintain D.O. level.	1) Decrease WAS rates by not more than 10% per day to bring process back to optimum parameters.	pg II-97 & II-36

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 4 — BULKING SLUDGE

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Clouds of billowing homogenous sludge rising and extending throughout the clarifier tank. Mixed liquor settles slowly and compacts poorly in settleability test, but supernatant is fairly clear.	A. Improper organic loading or D.O. level.	1. Check and monitor trend changes which occur in the following:	1) Decrease WAS rates by not more than 10% per day until process approaches normal operating parameters.	pg II-82 & II-36
		a. Decrease in MLVSS mg/l. b. Decrease in MCRT, Gould Sludge Age. c. Increase in F/M ratio. d. Change in D.O. levels.	2) Temporarily increase RAS rates to minimize solids carryover from clarifier tank. Continue until normal control parameters are approached.	pg II-29
		e. Sudden SVI increase from normal, or decrease in SDI.	3) D.O. level throughout aeration tank greater than 0.5 mg/l, preferably 1 to 3 mg/l.	pg II-24
	B. Filamentous organisms.	1. Perform microscopic examination of mixed liquor and return sludge. If possible, try to identify type of filamentous organisms, either fungal or bacterial.	1) If no filamentous organisms are observed, refer to Probable Cause "A" above.	
		2. If fungal is identified, check industries for wastes which may cause problems.	2) Enforce Industrial Waste Ordinance to eliminate wastes. Also see Remedy 4 below.	pg II-83

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 4 — BULKING SLUDGE (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
		3. If bacterial are identified, check influent wastewater and in-plant side stream flows returning to process for massive filamentous organisms.	3) Chlorinate influent wastewater at 5 to 10 mg/l dosages. If higher dosages are required, use extreme caution. Increase dosage at 1 to 2 mg/l increments.	
			4) Chlorinate RAS at 2 to 3 lbs/day/1000 lbs MLVSS.	pg II-89
			5) Optimized operational performance or upgrading of other in-plant unit processes will be required if filamentous organisms are found in side stream flows.	pg II-9
	C. Wastewater nutrient deficiencies.	1. Check nutrient levels in influent wastewater. The BOD to nutrient ratios should be 100 parts BOD to 5 parts total nitrogen to 1 part phosphorus to 0.5 iron.	1) If nutrient levels are less than average ratio, field tests should be performed on the influent wastewater for addition of nitrogen in the form a anhydrous ammonia, phosphorus in the form of trisodium phosphate and/or iron in the form of ferric chloride.	pg II-83, IV-12, & IV-15
		2. Perform hourly ML Settleability tests.	2) Observe tests for improvement in sludge settling characteristics with the addition of nutrients.	pg IV-14

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 4 — BULKING SLUDGE (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
	D. Low D.O. in aeration tank.	1. Check D.O. at various locations throughout the tank.	1) If average D.O. is less than 0.5 mg/l, increase air SCFM rate until the D.O. level increases to between 1 and 3 mg/l throughout the tank.	pg II-83
			2) If D.O. levels are nearly zero in some parts of the tank, but 1 mg/l or more in other locations, balance the air distribution system or clean diffusers. Refer to Troubleshooting Guide No. 1, Observation 2.	
	E. pH in aeration tank is less than 6.5	1. Monitor plant influent pH.	1) If pH is less than 6.5, conduct industrial survey to identify source. If possible, stop or neutralize discharge at source.	
			2) If the above is not possible, raise pH by adding an alkaline agent such as caustic soda or lime to the aeration influent.	pg II-86
		2. Check if process is nitrifying due to warm wastewater temperature or low F/M loading.	1) If nitrification is not required, increase WAS rate by not more than 10% per day to stop nitrification.	pg II-20, II-36 & IV-12
			2) If nitrification is required, raise pH by adding an alkaline agent such as caustic soda or lime to the aeration influent.	pg II-86

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 5 — SLUDGE CLUMPING

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Sludge clumps (from size of a golf ball to as large as a basketball) rising to and dispersing on clarifier surface. Bubbles noticed on clarifier surface. Mixed liquor in settleability test settles fairly well, however a portion of and /or all of the settled sludge rises to the surface within four hours after test is started.	A. Denitrification in clarifier.	1. Check for increase in secondary effluent nitrate level.	1) Increase WAS rate by not more than 10% per day to reduce or eliminate level of nitrification. If nitrification is required, reduce to allowable minimum.	pg II-90 & II-36
		2. Check loading parameters.	2) Maintain WAS rates to keep process within proper MCRT, Gould Sludge Age, and F/M ratio.	pg II-36
		3. Check D.O. and temperature levels in the aeration tank.	3) Maintain D.O. at minimum level (1.0 mg/l). Be sure adequate mixing is provided in the aeration tank.	pg II-24
		4. Check RAS rates and sludge blanket depth in clarifier.	4) Adjust RAS rate to maintain sludge blanket depth of 1 to 3 feet in clarifier.	pg II-29
	B. Septicity occurring in clarifier.	1. Refer to Troubleshooting Guide No. 1, Observation No. 2.		
		2. See 3 and 4 above.		

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 6 — CLOUDY SECONDARY EFFLUENT

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Secondary effluent from clarifier is cloudy and contains suspended matter. Mixed liquor in settleability test settles poorly, leaving a cloudy supernatant.	A. MLSS in aeration tank low due to process start-up.	1. Refer to Troubleshooting Guide No. 2, Observation No. 1.		
	B. Increase in organic loading.	1. Perform microscopic examination on mixed liquor and return sludge. Check for presence of protozoa.	1) If no protozoa are present, possible shock organic loading has occurred.	pg II-93 & IV-18
		2. Check organic loading on process.	2) Reduce WAS rate by not more than 10% per day to bring process back to proper loading parameters and increase RAS rates to maintain 1 to 3 foot sludge blanket in clarifier.	pg II-42 & II-36
		3. Check D.O. level in aeration tank.	3) Adjust air SCFM rate to maintain D.O. level within 1.0 to 3.0 mg/l.	pg II-24
	C. Toxic shock loading.	1. Perform microscopic examination on mixed liquor and return sludge. Check for presence of inactive protozoa.	1) If protozoa are inactive, possibility of recent toxic load on process. 2) Refer to Troubleshooting Guide No. 2, Observation No. 1-C.	pg II-93

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 6 — CLOUDY SECONDARY EFFLUENT (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
	D. Overaeration causing mixed liquor floc to shear.	1. Perform microscopic examination on mixed liquor. Check for dispersed or fragmented floc and presence of active protozoa.	1) Refer to Troubleshooting Guide No. 1, Observation No. 1-A.	pg IV-18
	E. Improper D.O. levels maintained in aeration tank.	1. Refer to Troubleshooting Guide No. 1, Observation No. 2.		

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 7 — ASHING AND PINPOINT/STRAGGLER FLOC

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Fine dispersed floc (about the size of a pinhead) extending throughout the clarifier with little islands of sludge accumulated on the surface and discharging over the weirs. Mixed liquor in settleability test, settles fairly well. Sludge is dense at bottom with fine particles of floc suspended in fairly clear supernatant.	A. Aeration tank approaching underloaded conditions (High MLSS) because of old sludge in system.	1. Check and monitor trend changes which occur in the following: a. Increase in MLVSS mg/l. b. Increase in MCRT, Gould Sludge Age. c. Decrease in F/M ratio. d. D.O. levels maintained with increasing aeration rates. e. Decrease in WAS rates. f. Decrease in organic loading (BOD/COD in primary effluent).	1) Increase WAS rates by not more than 10% per day to bring process back to optimum control parameters for average organic loading.	pg II-97 & II-36
		2. Check for foaming in aeration tank.	2) Refer to Troubleshooting Guide No. 2 for any foaming which may be occurring in aeration tank.	
			3) Adjust RAS rates to maintain sludge blanket depth of 1 to 3 feet in clarifier.	pg II-29
			4) Refer to Troubleshooting Guide No. 1 for additional observations.	

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 7 — ASHING AND PINPOINT/STRAGGLER FLOC (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
2. Small particles of ash-like material floating on clarifier surface.	A. Beginning of denitrification.	1. Stir floating floc on surface of 30-minute settling test.	1) If floating floc releases bubbles and settles, see Troubleshooting Guide No. 5, Probable Cause A. 2) If it does not settle, refer to Probable Cause B, below.	pg II-95 & II-93
	B. Excessive amounts of grease in mixed liquor.	1. Perform a grease analysis on MLSS, and check scum baffles in primary tank.	1) If the grease content exceeds 15 percent by weight of the MLSS, repair or replace scum baffles as needed.	pg II-95
		2. Check grease content in raw wastewater.	2) If grease content is excessive, implement an industrial waste monitoring and enforcement program.	pg II-95

ACTIVATED SLUDGE PROCESS
SECONDARY CLARIFIER

TROUBLESHOOTING GUIDE NO. 7 — ASHING AND PINPOINT/STRAGGLER FLOC (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
3. Particles of straggler floc about 1/4" or larger, extending throughout the clarifier and discharging over the weirs. Mixed liquor in settleability test, settles fairly well. Sludge does not compact well at the bottom with chunks of floc suspended in fairly clear supernatant.	A. Aeration tank slightly underloaded (Low MLSS) due to organic load change.	1. Check and monitor trend changes which occur in the following: a. Decrease in MLVSS mg/l. b. Decrease in MCRT, Gould Sludge Age. c. Increase in F/M ratio. d. Less aeration rate used to maintain D.O. e. Increase in WAS rates. f. Increase or decrease in organic loading (BOD/COD in primary effluent).	1) Decrease WAS rates by not more than 10% per day to bring process back to optimum control parameters for average organic loading.	pg II-97 & II-36
		2. Check for foaming in aeration tanks.	2) Refer to Troubleshooting Guide No. 2 for any foaming which may be occurring in aeration tank.	
			3) Adjust RAS rates to maintain sludge blanket depth of 1 to 3 feet in clarifier.	pg II-29
			4) Decrease aeration SCFM rates to maintain minimum D.O. of only 1.0 mg/l in aeration tank. Refer to Troubleshooting Guide No. 1 for additional observations.	pg II-24

REFERENCES

Eckenfelder, W.W., *Biological Waste Treatment,* Pergamon Press, New York, 1961.

Hawkes, H.A., *The Ecology of Waste Water Treatment,* Pergamon Press, Oxford, 1963.

Kerri, Kenneth D., et al., *(A Field Study Training Program), Operation of Wastewater Treatment Plants,* (Chapter 7), Sacramento State College Department of Civil Engineering.

McKinney, Ross E., *Microbiology for Sanitary Engineers,* McGraw-Hill Book Company Inc., New York, 1962.

Stevens, Thompson, Runyan, Inc., *Operator's Pocket Guide to Activated Sludge,* Parts I and II. Published by the Authors, 5505 S.E. Milwaukie Avenue, Portland, Oregon 97202, 1975.

Water Pollution Control Federation, *Operation of Wastewater Treatment Plants,* Manual of Practice No. 11, 1976.

West, Alfred W., *Operational Control Procedures for the Activated Sludge Process,* Parts I, II, IIIA, and IIIB, U.S. EPA, National Training and Operational Technology Center, Cincinnati, Ohio, 1975.

2.01 INTRODUCTION

Importance of a properly controlled operation.

The activated sludge process is reliable and has the ability to handle shock loads. It requires much more monitoring and control than the trickling filter process. Therefore, proper operation and control is essential to achieve optimum performance and to avoid operational problems. Table II-1 presents guidelines to achieving successful process control.

Acceptable ranges are given herein.

The operating parameters given in this section are intended as acceptable ranges to guide the operator in achieving operational control at his plant. Operation and control of a particular activated sludge process should be based on its response and performance as related to the control techniques applied. The success or failure in achieving the best possible performance from the treatment plant is dependent on the operator. There are five process control techniques presented under Waste Activated Sludge Control in this section of the manual. The operator should study each of these technqiues and apply the waste control program which he feels will provide the best effluent quality.

TABLE II-1

GUIDE TO SUCCESSFUL PROCESS CONTROL

REQUIREMENT	REFERENCE
1. Sound operational and preventive maintenance measures.	Section 2.02, OPERATIONAL GUIDES
2. Laboratory monitoring	Section 4.02, LABORATORY SAMPLING AND TESTING PROGRAM
3. Accurate, up-to-date records.	Appendix A, OPERATIONAL RECORDS
4. Evaluation of operational and laboratory data.	Section 4.03, LABORATORY CONTROL TESTS
5. Application of data to adjustment of the process.	Section 2.04, PROCESS CONTROL
6. Troubleshooting problems before they become serious.	Section 1.02, TROUBLESHOOTING GUIDES

2.02 OPERATIONAL GUIDES

Operational guides are provided on the following pages to aid the operator in establishing routine operational procedures for his activated sludge process.

Competent preventive maintenance program is essential.

Performance of the routine operational procedures is by no means complete without a competent preventive maintenance program. Every item of operating equipment requires frequent attention, with particular emphasis on lubrication and other preventive maintenance requirements essential to a trouble-free operation and minimum maintenance costs. A good preventive maintenance program helps to improve process performance through a longer more dependable equipment life.

2.03 PERFORMANCE EVALUATION

Competent process control includes evaluation of process performance.

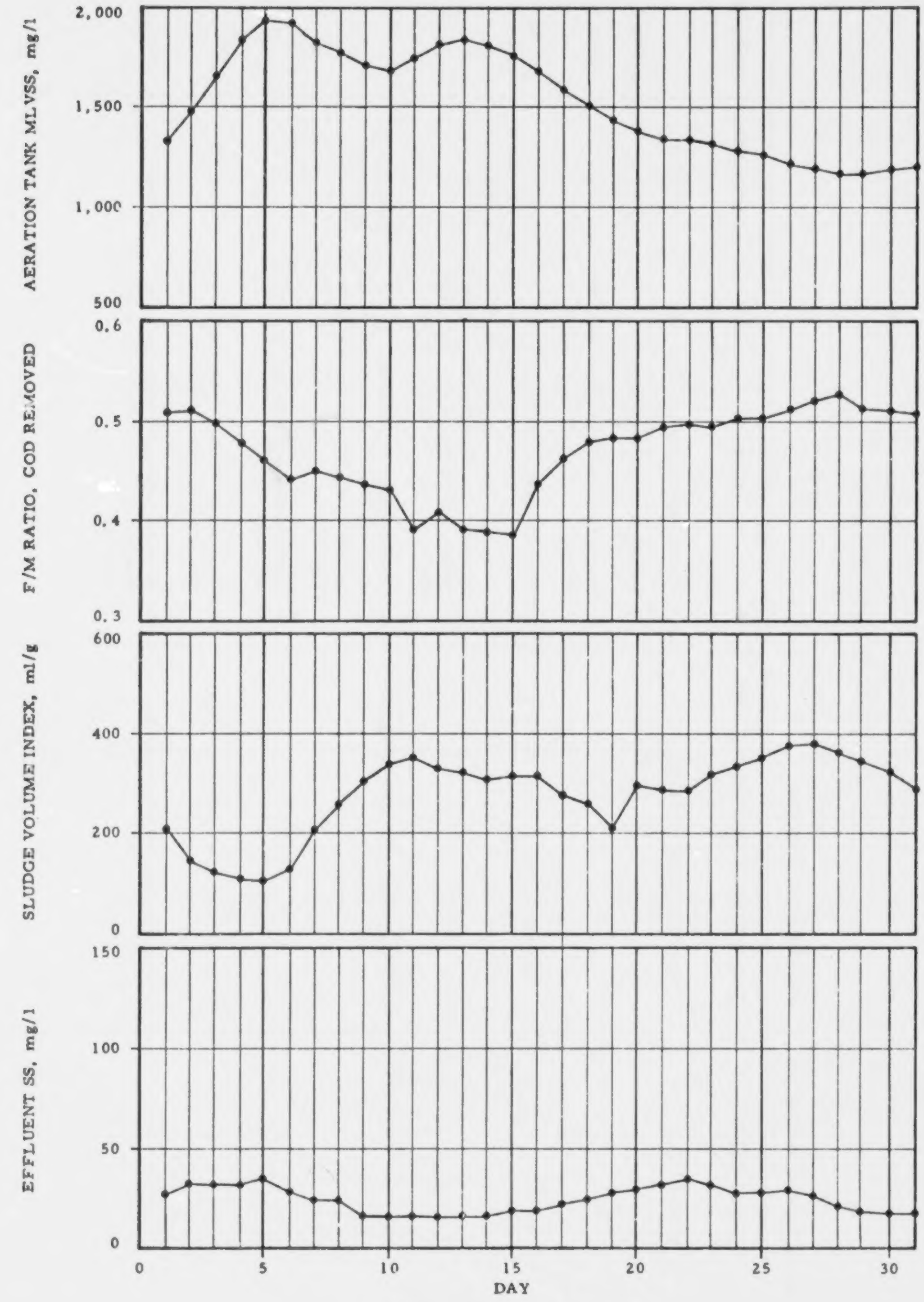
Evaluation of process performance is an essential part of compentent process control and operation. The evaluation is helpful in determining process response to various modes of operation, developing performance trends, and identifying the causes of operational problems. For the activated sludge process, performance evaluation consists of reviewing the BOD, COD, suspended matter, and nitrogen removal efficiencies to the mode of operation, F/M parameters, and RAS and WAS rates in relationship to control parameters such as MCRT, Gould Sludge Age, and sludge quality. The review and application of lab testing results is further discussed in Section IV - "LABORATORY CONTROL" and "APPENDIX A".

Many factors affect process performance.

Performance of the activated sludge process is affected by many factors such as: hydraulic and organic loadings, method of wastewater distribution to multiple tanks, characteristics of applied wastewater (temperature, pH, toxicants, etc.), and performance of other treatment units in the plant. An effective means of reviewing your plant performance is to maintain daily charts or graphs reflecting such data against time. The charts presented in Figure II-1 serve as visual aids in identifying the optimum control parameters and make any trends or changes immediately evident. The preparation and use of these trend charts are discussed further in "APPENDIX A".

Importance of complete and accurate records.

Conclusions reached during the process evaluation are then applied to the adjustment of the process (basically adjustment of RAS, WAS and aeration rates) for an efficient and economical operation. Whenever possible, only one process adjustment should be made at a time to allow sufficient time between each change for the process to respond and stabilize. This is especially true when decisions are made to adjust F/M, MCRT and Gould Sludge Age, since these parameters are directly related to changes in WAS rate. Complete and accurate records of all phases of plant operations and maintenance are essential for accurate performance evaluation and process control. The preparation of operational records is discussed further in "APPENDIX A".



ACTIVATED SLUDGE PROCESS
(Five-day moving average trend plots)

FIGURE II-1

ACTIVATED SLUDGE PROCESS

OPERATIONAL GUIDE NO. 1 — AERATION SYSTEM

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
A. Aeration tank.	1. Inspect for proper operation.	1a. Mechanical equipment.	Twice/shift	
		1b. Presence of foaming on surface.		TG No. 2
		1c. Boiling or uneven surface aeration pattern.		TG No. 1
	2. Check D.O. level.	2a. D.O. in range of 1.0 to 3.0 mg/l.	Every 2 hrs.	pg II-26
	3. Perform routine washdown.	3a. Hose down inlet channels, tank walls—especially at the water line, effluent baffles, weirs and channels, and other appurtenant equipment at water line.	Daily to weekly	
	4. Check control gates and gate operators for proper operation.	4a. Operate gates and operators to full open and close position. Adjust gates to proper position to equalize flow distribution.	Twice/month to monthly	
		4b. Lubricate as recommended by manufacturer.		
	5. Check froth spray system, if provided.	5a. Unplug spray nozzles as necessary and check for proper spray angle.	Twice/shift	
	6. Inspect baffles and effluent weirs.	6a. Maintain baffles in good condition. Maintain effluent weirs at equal evaluation.	Monthly	pg II-78

ACTIVATED SLUDGE PROCESS

OPERATIONAL GUIDE NO. 1 — AERATION SYSTEM (continued)

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
B. Aeration Piping.	1. Inspect piping for leaks.	1a. Visually observe and listen for leaks at pipe and joint connections.	Daily	TG No. 1 Observation No. 3 pg III-4
	2. Inspect diffuser header assemblies.	2a. Remove header assemblies from tank. Check diffusers and connections for damage and plugging.	Twice/year	
	3. Check aeration pipe valves and diffuser header assembly control valves for proper operation.	3a. Operate valves to full oper and close position. Adjust valves to proper positons.	Monthly	TG No. 1, Observation No. 2
	4. Check air flow meters, gauges and condensate traps.	4a. Check and calibrate meters and gauges as recommended by manufacturer.		
		4b. Drain condensate traps.	Daily	
C. Air Compressors (Centrifugal and positive placement)	1. Check air filters.	1a. Clean or replace filters as recommended by manufacturer.	Generally dictated by climatic conditions	
	2. Check operation of compressors and motors.	2a. Check for excessive vibrations, unusual noises, lubricant leakage, bearing overheating.	Twice/shift	
		2b. Check oil levels, if so equipped, maintain proper levels.		
		2c. Check packing, mechanical seals—adjust and maintain as recommended by manufacturer.		
		2d. Check compressor intake and discharge valves for proper position.		

ACTIVATED SLUDGE PROCESS

OPERATIONAL GUIDE NO. 1 — AERATION SYSTEM (continued)

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
	3. Check compressor air discharge back pressure.	3a. Record back pressure. Increasing pressure is indicative of diffuser plugging.	Daily	TG No. 1, Observation No. 3
	4. Perform regualr maintenance as recommended by manufacturer.			
	5. Alternate compressors in service.		Daily to weekly	
D. Mechanical aerators.	1. Check units for proper operation.	1a. Check for excessive vibration, unusual noises, motor and gear box overheating.		
		1b. Check for proper oil level in gear box and proper motor lubrication.	Twice/shift	
		1c. Check condition of baffles—if so equipped, and repair or replace as required.		
	2. Maintain units properly.	2a. Follow manufacturer's instructions.		

ACTIVATED SLUDGE PROCESS

OPERATIONAL GUIDE 2 — SECONDARY CLARIFIER

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
A. Clarifier	1. Inspect for proper operation.	1a. Mechanical equipment.	Twice/shift	pg II-77
		1b. Presence of suspended sludge.		TG No. 3, 4, 5, 6, 7
	2. Perform daily washdown.	2a. Hose down the influent channels, tank walls—especially at the water line, effluent weir and launders, effluent channel and center feed baffles.	Daily to weekly	
	3. Maintain sludge collection equipment and drive units.	3a. Follow manufacturer's instructions.		
	4. Inspect baffles and effluent weirs.	4a. Maintain baffles in sound condition.	Monthly	pg II-78
		4b. Maintain effluent weirs at an equal elevation.		pg II-78
	5. Check sludge blanket depth	5a. Sludge should be removed to maintain a blanket depth of 1 to 3 feet. Adjust RAS rates as necessary.	Twice/shift or more frequently	pg II-29
	6. Check D.O. level in clarifier before discharging over effluent weirs.	6a. D.O. level should be maintained at minimum of 0.5 mg/l. Adjust aeration air as necessary.	Twice/shift	pg II-24
	7. Check gates and operators for proper operation.	7a. Operate gates and operators to full open and close position. Adjust gates to proper position to equalize flow distribution.	Twice/month to monthly	

ACTIVATED SLUDGE PROCESS

OPERATIONAL GUIDE 3 — PUMPING EQUIPMENT AND PIPING IN RAS AND WAS SYSTEMS

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
A. Pumps	1. Check operation of the pumps and motors.	1a. Check for excessive vibration, unusual noises, lubricant leakage, and overheating.	Twice/shift	
		1b. Check oil reservoir level—if so equipped.		
		1c. Check oil feed rate—if so equipped.		
		1d. Check packing or mechanical seals—make adjustment per manufacturer's instructions.		
		1e. Check position of suction and discharge valves.		
		1f. Check pump suction and discharge pressure—if so equipped.		
	2. Aternate pumps in service.		Daily to weekly	
	3. Maintain pumping units.	3a. Follow manufacturer's instructions.		
	4. Fully open and close all valves.	4a. Make necessary adjustments or repairs.	Monthly	
		4b. Maintain valves and operators according to manufacturer's instructions.		
	5. Check operation of air vacuum and air relief valves.	5a. Maintain according to manufacturer's instructions.	Weekly	
	6. Check operation of any pump controls and instrumentation, such as flow meters, density meters, control signal loop.	6a. Maintain according to manufacturer's instructions.	Daily	

Review of In-Plant Recycled Flows

Recycled flows may cause overloading.

In evaluating the performance of the process or in trying to solve problems, careful consideration should be given to all in-plant recycled flows. Often, in-plant recycled flows are the cause of organic or hydraulic overloading. The sludge processing operations may return decants from digesters, thickeners, centrifuges, or vacuum filters. The waste backwash water from effluent sand filtration processes may also cause hydraulic overloading or other process control problems. The recycled flow from improperly operated sludge processing units may account for as much as 25 percent of the total plant organic loading. Usually, the majority of recycled flows are passed back to primary sedimentation units where it is hoped organic solids will settle out. In most cases this practice is the major cause of overloading biological processes due to poor removal of solids in the recycled flows sent to the primary sedimentation units.

The additional loading will then result in a greater sludge production, and subsequently an increased loading upon the sludge processing operation. In the activated sludge process, excessive BOD or COD loadings will eventually reduce effluent quality and possibly cause anaerobic conditions to occur in the process.

Minimize the effect of recycled flows.

Some guidelines that will reduce the effects of recycled flows on the activated sludge process include the following:

1. Add flow continuously or during low night flows to avoid shock loads.
2. Improve efficiency of sludge handling process.
3. Utilize a lagoon or drying bed for poor quality decants from sludge processing operations.
4. Avoid pumping excess water to sludge handling processes.
5. Aerate or pretreat recycled flows to reduce oxygen demands.

Aeration Performance

Aeration is important to microorganisms.

A great deal can be learned about the operation of an activated sludge process by reviewing aeration requirements and performance. Basically, the mixed liquor is a suspension of microorganisms that consume the organic matter in the wastewater while utilizing dissolved oxygen and releasing carbon dioxide to produce new cell growth.

Two basic paramenters to use.

The air requirement is dependent upon the oxygen transfer rate to the mixed liquor and the utilization of the dissolved oxygen by the microorganisms. The oxygen transfer rate is chiefly dependent on the design of the aeration system. The rate of dissolved oxygen utilization is dependent upon the microorganism activity as it relates to organic loading, pH, temperature, aeration period and availability of dissolved oxygen. The air requirements may be based on more than one parameter. The most frequently used parameters by operators include the amount of air applied per pound COD or BOD removed (CF air/lb removed) in the process and the amount of air applied per gallon of wastewater treated (CF air/gal). Typical aeration rates for these parameters are presented in Table II-2.

TABLE II-2

TYPICAL AIR REQUIREMENT PARAMETERS

Diffused Aeration System			Mechanical Aeration System System	
CF Air/lb Removed		CF Air/Gal	lbs O_2 lbs Removed	
COD	BOD		COD	BOD
1000 - 2000	800 - 1500	0.5 - 3.0	1.5 - 1.8	1.0 - 1.2

Aeration requirements change when process is nitrifying.

When evaluating aeration requirements, remember that the 5-day BOD, and the COD only reflect the carbonaceous portion of the organic loading and not the nitrogenous portion of the organic loading. The aeration requirements will be affected by the degree of nitrification as it relates to the nitrogenous strength of the organic loading as well as by the wastewater temperature and pH.

The aeration performance parameters can be determined as follows:

How to calculate CF Air/lb removed.

Example Calculation

A. Data Required
   1. COD or BOD removed, lbs/day = 22,000 BOD
   2. Total Air applied, CF/day = 31,900,000

B. Determine CF air/lb COD or BOD removed.

$$\text{CF Air/lb removed} = \frac{\text{Total air applied}}{\text{BOD, lbs/day}}$$

$$= \frac{31{,}900{,}000}{22{,}000}$$

$$= 1450$$

How to calculate CF Air/gal

Example Calculation

A. Data Required:
   1. Total air applied, CF/day = 31,900,000
   2. Total influent flow/day to aeration tank, gpd = 13,000,000 (exclude RAS flow rate)

B. Determine CF air/gal wastewater treated

$$\text{CF air/gal} = \frac{\text{Total air applied}}{\text{Total flow, gpd}}$$

$$= \frac{31{,}900{,}000}{13{,}000{,}000}$$

$$= 2.4$$

Example Calculation

How to calculate lbs O_2/lb removed using mechanical aerators.

A. Data Required

1. COD or BOD removed, lbs/day = 7200 BOD
2. n = Number of aerators in service = 3
3. hp = horsepower per aerator = 100
4. FTR = Field transfer rate, each aerator, lbs O_2/hp/hr = 2 (supplied by aerator manufacturer)
5. T = Time aerators in service, days = 0.83*

*This is determined by dividing the time each aerator is in service by 24 hours/day: $\frac{\text{Hours in service}}{\text{24 hours/day}}$ = days

B. Determine lbs O_2/lb COD or BOD removed

$$\text{lbs } O_2\text{/lb removed} = \frac{(n \times hp \times FTR \times T \times 24 \text{ hrs/day})}{\text{COD or BOD removed, lbs/day}}$$

$$= \frac{(3 \times 100 \times 2 \times 0.83 \times 24)}{7200}$$

$$= \frac{15{,}936}{7200}$$

$$= 1.6$$

Solids Inventory

Microorganisms relationship to MLVSS.

The amount of suspended matter (SS) that makes up the mixed liquor consists of living and nonliving organic matter. The living organic matter is referred to as being "active." The "active" portion of the SS is of major importance because included in this portion are the microorganisms responsible for treating the wastewater. The more accurately the concentration of active microorganisms is known, the more consistently the activated sludge process can be controlled.

Typically 70-80% of the MLSS is volatile.

Many attempts have been made to accurately measure the "active" concentration of the SS. The most common means of estimating the microorganism concentration is the measurement of volatile suspended matter (VSS). All the organic material in the SS burns to carbon dioxide and water in the VSS determination. Typically, 70-80 percent of the MLSS will be VSS. The VSS determination provides a crude approximation of the concentration of living biological solids because the VSS also includes a nonliving fraction. Even so, the VSS has been found to be an acceptable representation of "active" living microorganisms in activated sludge.

A key to successful process control is representative MLSS sampling.

Samples of MLSS must be taken at several locations in the aeration tank to ensure that a representative sample of the microorganism concentration is collected. In general, each compartment of an aeration tank must be sampled. Similarly, aeration tanks that are long and narrow must be sampled at both ends and at a midpoint to ensure that a representative sample of the mixed liquor is collected. Sampling techniques to obtain representative MLSS samples are discussed in Section IV - "LABORATORY CONTROL".

Good sampling procedures are essential for making a meaningful estimate of the microorganism concentration, and samples for MLSS must be taken using a consistent technique. There are two acceptable approaches for obtaining a mixed liquor sample:

1. Composite samples may be taken at consistent intervals throughout the day from the same locations in the aeration tank.
2. Grap samples taken at the same time each day at the same locations in the aeration tank.

Either of these approaches will produce suitable samples. The first method requires a refrigerated automatic sampler while the second method has the advantages of not depending on a sophisticated sampler and of developing a routine for sampling and observation of the aeration tank. Other methods of sampling, such as grab samples taken at various times will produce less satisfactory estimates of the MLSS.

Accurate MLVSS samples very important

The importance of the MLSS samples cannot be over emphasized. It is important to remember that accurate and representative samples are the key to controlling the activated sludge process.

Calculating the Solids Inventory

MLSS samples used to calculate the Volatile Solids Inventory

The purpose of collecting samples of MLSS is to develop an estimate of the amount of microorganisms in the treatment system by determining the VSS content in the MLSS. The amount of microorganisms (VSS) in the treatment system is the solids inventory. The solids inventory must be known in order to properly control the activated sludge process.

Solids Inventory varies directly with MCRT

The solids inventory is used to determine F/M, MCRT and the amount of activated sludge that should be wasted. The solids inventory varies directly with the MCRT, that is as the MCRT increases the solids inventory increases. It also varies inversely with the F/M, that is, as the F/M increases the solids inventory decreases.

Should solids in the clarifier be measured in solids inventory?

A recurring discussion in the technical literature involves the question of whether the solids in the clarifier should be considered as part of the solids inventory. At present, there is no one answer to the question; however, all calculations involving F/M or MCRT must be made using the same solids inventory.

Arguments against.

There are three basic arguments for not including the solids in the clarifier. First, the microorganisms in the system cannot grow due to food and oxygen limitations when they are in the clarifier. Second, loading parameters for the activated sludge process were first developed on the basis of pounds of BOD applied per 1,000 cubic feet of aeration tank, which ignores the solids in the clarifier. Third, the amount of solids in the clarifier is not a very significant (less than 10 percent of the total) fraction of the total solids in the process.

Argument for.

The argument in favor of including the clarifier solids in the solids inventory is simply that these solids are significant and they cannot be ignored. Additionally, if all of the solids are included in the calculations there is less likelihood of making an error in the total solids inventory that exists in the process. Finally, errors in the inventory amount would most likely be significant at times when operational problems are experienced - i.e. when the sludge is not settling well in the clarifier.

In general, no need to measure these solids.

The consequences of ignoring the solids in the clarifier will not affect process control adjustments in most cases; and it is suggested that operators use this approach when determining the solids inventory. If ignoring the solids in the clarifier makes process control inconsistent as observed by variations in effluent quality, then the operator should consider including the clarifier solids when he determines the solids inventory.

Solids inventory for a typical activated sludge process may be calculated as follows:

How to calculate solids inventory in the aeration tank.

Example Calculation

A. Data Required:
  1. Aeration tank volume, mg = 1.2
  2. Number of tanks in service = 2
  3. MLSS concentration, mg/1 = 2200
  4. Percent VSS in MLSS, $\frac{\%}{100}$ = .72

B. Determine total pounds VSS in aeration tank.

$$\text{lbs VSS inventory}_{\text{Aer. tank}} = \text{(Aer. Tank Vol.) (No. of tanks) (MLSS) (\% VSS) (8.34 lbs/gal.)}$$

$$= (1.2)(2)(2200)(.72)(8.34)$$

$$= 31{,}705$$

How to calculate the secondary clarifier solids inventory.

If the clarifier is included in determining the solids inventory, the volume of sludge in the clarifier must be determined by measuring the sludge blanket in the clarifier and obtaining an average depth. The depth measurement from the water surface to the top of the sludge blanket is subtracted from the average clarifier depth to determine the average sludge depth in the clarifier. The average sludge depth is then multiplied by the surface area of the clarifier to obtain the volume expressed as cubic feet which must be multiplied by 7.48 gal/cu ft and divided by one million to convert the volume to million gallons (mg) of sludge.

The average VSS concentration of the sludge in the clarifier is roughly estimated by assuming the top of the sludge blanket is equal to the MLVSS concentration and the bottom of the sludge blanket is equal to the VSS_{RAS} concentration. These two concentrations are then averaged to estimate the concentration of the clarifier sludge.

The pounds of solids inventory (VSS) in the clarifier may be determined and added to the aeration tank inventory as follows:

Example Calculation

1. MLVSS concentration, mg/l = 1584
2. VSS_{RAS} concentration, mg/l = 3330
3. Clarifier depth, ft. = 10
4. Depth from water surface to sludge blanket (DOB), ft. = 8
5. Clarifier surface area, sq. ft. = 4415

B. Determine the volume of sludge in the clarifier.

$$\text{sludge vol., mg} = \frac{(\text{Clarifier depth, ft. - DOB, ft.})(\text{Surface area, sq. ft.})(7.48 \text{ gal/cu. ft.})}{1{,}000{,}000}$$

$$= \frac{(10\text{-}8)(4415)(7.48)}{1{,}000{,}000}$$

$$= 0.066$$

C. Determine the average VSS concentration of the clarifier sludge.

$$\text{avg. VSS, mg/l} = \frac{\text{MLVSS, mg/l} + VSS_{RAS}\text{, mg/l}}{2}$$

$$= \frac{1584 + 3330}{2}$$

$$= 2457$$

D. Determine total pounds of VSS in the clarifier.

VSS, lbs, = (avg conc., mg/l) (sludge vol., mg) (8.34 lbs/gal)
in clarifier

$$= (2457)(0.066)(8.34)$$

$$= 1{,}352$$

E. Determine the total VSS inventory by adding the clarifier VSS inventory to the aeration tank VSS inventory.

Total VSS, lbs = MLVSS, lbs + Clarifier VSS, lbs

= 31,705 + 1,352

= 33,057

COD/BOD and Suspended Matter Removal

What are the reliable indicators of process performance?

The activated sludge process is designed to remove a high percentage of the COD/BOD and suspended matter when operated within the proper loading range. The removal efficiency of these constituents are very reliable indicators of process performance. If the efficiency drops below the expected design performance, action should be taken to locate the reason for the decreased efficiency. Operational records, process control parameters, lab analysis, and wastewater characteristics should be reviewed and analyzed when trying to locate the problem. The information gained from the evaluation should be implemented into the operation of the unit process. The best practice when making operational changes is to make one change at a time and then allow sufficient time (usually two to four weeks) between changes for stabilization of the biological process.

Suspended matter is related to BOD.

The activated sludge process is also designed to produce an effluent having a suspended matter content of 20 mg/l or less when operated within the proper loading range. Much of the secondary effluent BOD will be directly related to the amount of suspended matter that has escaped with the clarifier effluent flow. Careless operational procedures will result in an increased secondary effluent BOD. Hence, the evaluation of the unit process performance in regard to the suspended matter removal is valuable in improving both the suspended matter and COD/BOD removals. An increase of the secondary effluent suspended matter is an indication that the process is not performing as it should. The process control parameters, operational records, and wastewater characteristics should be reviewed and analyzed to determine what action should be taken to restore the desired process performance. For guidance in the troubleshooting of high effluent suspended solids, refer to Section I, "TROUBLESHOOTING".

COD/BOD removal expressed as %.

The COD/BOD and suspended matter removals are normally expressed as percentages. These parameters should be recorded daily. The COD/BOD and suspended matter removals are all calculated by using the same formula. The example calculation given below shows how to determine the suspended matter removal efficiency.

Example Calculation

A. Data Required

1. Primary effluent suspended matter, mg/l = 160 (COD or BOD)

2. Secondary effluent suspended matter; mg/l = 14 (COD or BOD)

B. Determine percent removal of suspended matter.

$$\text{Removal efficiency, \%} = \frac{\text{Influent SS - effluent SS}}{\text{Infuent SS}} \times 100$$

$$= \frac{160 - 14}{160} \times 100$$

$$= 91$$

Process Kinetics

Kinetics are math short hand for controlling the process.

A great deal of effort and a large number of publications have been put forth to describe the activated sludge process. The major accomplishment of these efforts has been the development of an approach to activated sludge design and operation that is based on the kinetics of microorganism growth. The term kinetics normally refers to the rate at which chemical or biological reactions occur; however, microorganism growth kinetics are nothing more than expressions that relate organic loading to the production of new microorganisms.

The concepts of activated sludge kinetics enables engineers to design wastewater treatment plants on a logical and systematic basis.

There are two basic concepts, the food to microorganism ratio (F/M) and the mean cell residence time (MCRT), that are expressed in the form shown below:

F/M

$$\text{Food to microorganism ratio} = F/M = \frac{\text{lbs COD applied per day}}{\text{lbs VSS inventory}}$$

MCRT

$$\text{Mean cell residence time} = MCRT = \frac{\text{lbs solids inventory}}{\text{lbs VSS produced per day}}$$

Kinetic Relationships

F/M, MCRT, K_D, Y

The F/M and the MCRT are related by two constants that are called the Yield coefficient, Y and the Endogenous Decay coefficient, K_D. The Yield coefficient expresses the ratio of the amount of microorganisms produced to the amount of food (BOD or COD) consumed. The Yield coefficient is measured by operating the activated sludge process at several values of MCRT. Typical values of Y based on COD, for domestic wastewater range from 0.3 to 0.4 lbs VSS produced/lb COD removed. The Endogenous Decay coefficient expresses the decrease in active mass of microorganisms due to endogenous metabolism. This coefficient is typically about 0.05 lbs VSS decayed per day/lb solids inventory.

MCRT related to the F/M.

The MCRT is related to the F/M as shown below:

$$\text{MCRT, days} = \frac{1}{(Y)\,(F/M)\,(\text{Removal efficiency}) - K_D}$$

where,
y = lbs. VSS produced per lb. COD removed per day

$$F/M = \frac{\text{lbs. COD applied per day}}{\text{lbs. VSS inventory}}$$

$$\text{Removal efficiency} = \frac{\text{Influent COD, mg/l - Effluent COD}^{*}\text{, mg/l}}{\text{Influent COD, mg/l}} \times 100$$

K_D = lbs. VSS decay per day per lb. VSS inventory

*Soluble COD, see Section IV, "LABORATORY CONTROL".

The following example calculations show the interrelationship of MCRT, microorganism growth, and F/M.

Example Calculation

A. Data Required
  1. F/M = 0.55 lbs COD applied/day/lb MLVSS
  2. Y = 0.35 lbs VSS produced per lb COD removed
  3. K_D = 0.05 lbs decay per day/lb MLVSS
  4. Eff. × COD removal efficiency × 90% (0.90)
  5. MCRT = 8.1 days
  6. Y_{net} = Net sludge yield = 0.249 lbs VSS per lb COD removed/day

How to calculate MCRT.

B. Determine the MCRT using kinetics.

$$\text{MCRT, days} = \frac{1}{(Y)\,(F/M)\,(\text{eff}) - K_D}$$

$$= \frac{1}{(0.35)\,(0.55)\,(0.90) - 0.05}$$

$$= \frac{1}{0.173 - 0.05} = \frac{1}{0.123}$$

$$= 8.1$$

This indicates that an amount of VSS equal to the solids inventory must be wasted from the process in a 8.1 day period to maintain a constant MCRT.

How to calculate Y as a ratio.

C. Determine the net sludge yield (net growth rate) expressed as a ratio of lbs VSS/lb COD removed/day.

$$Y_{net}, \text{ratio} = \frac{1}{(\text{MCRT})(\text{F/M})(\text{Eff.})}$$

$$= \frac{1}{(8.1)(0.55)(0.90)}$$

$$= 0.249 \text{ lbs VSS/lb COD removed/day}$$

How to calculate Y as %/day.

D. Determine the net sludge yield (net growth rate) expressed as percent of the solids inventory (SI).

$$Y_{net}, \text{\%/day} = (Y_{net}, \text{ratio})(\text{F/M})(\text{Eff})(100\%)$$

$$= (0.249)(0.55)(0.90)(100\%)$$

$$= 12.3\ \% \text{ of solids inventory}$$

OR

$$Y_{net}, \text{\%/day} = [(Y)(\text{F/M})(\text{Eff}) - K_D]\ 100\%$$

$$= [(0.35)(0.55)(0.90) - 0.05]\ 100\%$$

$$= [0.173 - 0.05]\ 100\%$$

$$= 12.3\% \text{ of solids inventory}$$

This indicates that about 12.3 percent of the solids inventory would have to be wasted per day to maintain a constant MLVSS or F/M assuming that other conditions are not changing significantly.

How to calculate F/M when MCRT, Y and % efficiency is known.

E. Determine the F/M when the MCRT, net sludge yield, and removal efficiency are known.

$$\text{F/M} = \frac{1}{(\text{MCRT})(Y_{net})(\text{Eff.})}$$

$$= \frac{1}{(8.1)(0.249)(0.90)}$$

$$= 0.55 \text{ lbs COD applied/lb solids inventory}$$

Solids inventory must always be calculated same way.

All the kinetic calculations must be based on the same solids inventory—either the MLVSS under aeration or the total VSS in the activated sludge process.

Table II-3 presents the relationship of MCRT to F/M for two values of the Yield coefficient.

Approximate relationship of the MCRT to the F/M.

TABLE II-3

APPROXIMATE RELATIONSHIP OF THE F/M TO THE MCRT

(K_D = 0.05 per day)

	*F/M Range (COD)	
MCRT	Y = 0.3	Y = 0.4
20	0.33	0.25
15	0.39	0.29
10	0.50	0.38
7.5	0.61	0.46
5	0.83	0.63
2.5	1.50	1.13

A similar table can be developed for the relationship of MCRT and F/M when BOD is used instead of COD. A typical range of values for the Yield coefficient for domestic wastewater on a BOD basis is 0.5 to 0.6 lbs MLVSS produced per lb of BOD removed. The value of K_D remains at 0.05 per day. Table II-4 presents the relationship of the MCRT to the F/M for two values of the Yield coefficient:

TABLE II-4

APPROXIMATE RELATIONSHIP OF THE F/M TO THE MCRT

(K_D = 0.05 per day)

	* F/M Range (BOD)	
MCRT	Y = 0.5	Y = 0.6
20	0.20	0.17
15	0.23	0.19
10	0.30	0.25
7.5	0.37	0.30
0.50	0.42	
3	0.77	0.64

*F/M expressed as lbs removed/day/lb VSS inventory. To express the F/M as lbs applied/day/lb VSS inventory, divide the F/M presented in the Table by the removal efficiency (as %) of the treatment process.

Nitrification

Some plants are designed to nitrify.

Many activated sludge processes are designed to attain a high degree of nitrification. This section is devoted to evaluation of the process performance based on nitrification.

What establishes nitrification?

The degree of nitrification that must be attained in the activated sludge process is dictated by the maximum allowable limit of ammonia nitrogen discharged with the final effluent. This limit is usually governed by the NPDES permit issued by State or Federal regulatory agencies.

How does nitrification occur?

In fresh wastewater the nitrogen present predominates as organic nitrogen. As the organic matter in the wastewater decomposes, a portion of the organic nitrogen is converted to ammonia nitrogen. When the wastewater is sufficienty aerated, nitrifying bacteria will convert the ammonia nitrogen to nitrite nitrogen and subsequently to nitrate nitrogen. Nitrate represents the final form of nitrogen resulting from the oxidation of nitrogenous compounds in the wastewater. The nitrogen cycle is illustrated in Figure II-2.

What achieves nitrification?

To achieve the desired degree of nitrification, the Mean Cell Residence Time must be long enough (usually 10 days plus) to allow the nitrifying bacteria sufficient time to convert nitrogenous compounds to nitrate nitrogen. Since the nitrifying bacteria grow much slower than the bacteria utilizing the carbonaceous compounds, it is possible to waste the nitrifying bacteria from the system at a higher rate than their growth rate.

What affects nitrification?

The factors affecting the growth rate of the nitrifying bacteria are primarily, DO, pH, temperature, and the availability of nitrogenous food.

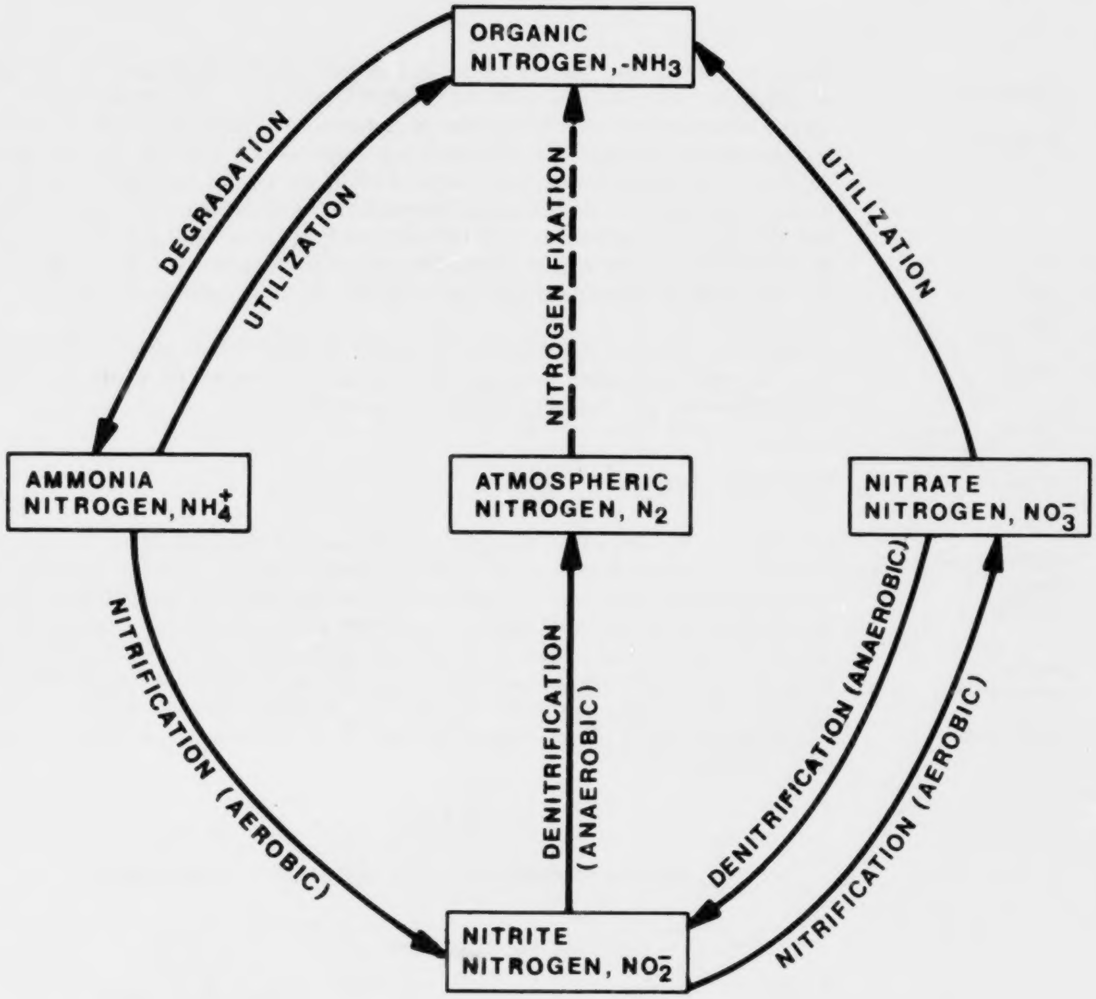
The DO in the aeration tank must usually be 1.0 mg/l or greater when operating the process to nitrify. Nitrification exerts a substantial oxygen requirement. The oxygen requirement may be calculated as follows:

$$NH_3\text{, oxidation} = \text{lbs } NH_3 \times 4.6 = O_2 \text{ lbs/day}$$

The optimum pH range is 7.9 to 8.9; however, the range of 7.6 to 7.8 is recommended in order to allow escape of the carbon dioxide to the atmosphere. Theoretically, 7.1 lbs of $CaCO_3$ alkalinity are destroyed per pound of ammonia nitrogen oxidized, thus resulting in a decreasing pH within the aeration tank.

The optimum temperature range is 15° to 35° C. The growth rate of nitrifying bacteria increases as the wastewater temperature increases and conversely it decreases as the wastewater temperature decreases. Since there is no control over the wastewater temperature, compensation for slower winter growth rates by increasing the MCRT and maintaining the pH within the recommended range must be made.

The growth rate of nitrifying bacteria is affected very little by the organic load applied. However, the population of the nitrifying bacteria will be limited by the amount of nitrogenous food available in the wastewater.


ORGANIC NITROGEN, -NH3
DEGRADATION
UTILIZATION
NITROGEN FIXATION
UTILIZATION
AMMONIA NITROGEN, NH4+
ATMOSPHERIC NITROGEN, N2
NITRATE NITROGEN, NO3-
NITRIFICATION (AEROBIC)
DENITRIFICATION (ANAEROBIC)
DENITRIFICATION (ANAEROBIC)
NITRIFICATION (AEROBIC)
NITRITE NITROGEN, NO2-

SOLID LINES SHOW IMPORTANT PATHWAYS IN THE BIOLOGICAL TREATMENT OF WASTEWATER. THE BROKEN LINE FOR NITROGEN FIXATION IS ONLY ADDED TO COMPLETE THE CYCLE.

APPROXIMATELY 60 TO 80% OF THE NITROGEN IN RAW DOMESTIC WASTEWATER IS IN THE FORM OF AMMONIA NITROGEN. THE REST IS PRIMARILY IN THE FORM OF ORGANIC NITROGEN.

WASTEWATER NITROGEN CYCLE

FIGURE II-2

Considerations for nitrification.

When reviewing the performance of the activated sludge process for the selection of an optimum F/M ratio; MCRT or Gould Sludge Age must be considered along with nitrification requirements. These parameters should be selected to provide the degree of nitrification required by the discharge permit. IF the ammonia nitrogen limit is being exceeded, the MCRT or Gould Sludge Age should be increased. Increasing these parameters will increase the MLVSS and consequently decrease the F/M ratio. With the other conditions constant, a definite relationship will exist between the weight ratio of the ammonia nitrogen oxidized per day to the MLVSS under aeration.

The growth of cell mass from the oxidation of ammonia is about 0.05 lbs per lb of ammonia nitrogen oxidized. As a result the degree of nitrification will have little effect on the next sludge yield and WAS rates.

Secondary Clarifiers

Clarifiers serve a dual purpose.

How to calculate surface overflow rate.

Clarifiers in the activated sludge process serve a dual purpose. They must provide a clarified effluent and a concentrated source of return sludge for maintaining process control. Adequate area and depth is essential to allow the aeration tank effluent (MLSS) to settle and compact without carry over of solids in the clarified effluent. To prevent solids carry over, secondary clarifiers are designed to be operated within given parameters. These parameters include the surface overflow rate (gpd/sq. ft.) and solids loading rate (lbs solids/day/sq. ft.). Typical ranges for these parameters are presented in Table II-5.

TABLE II-5*

TYPICAL DESIGN PARAMETERS FOR SECONDARY CLARIFIERS

Process Variation	Surface Overflow Rate gpd/sq ft		Solids Loading[1] lb solids/day/sq ft		Depth ft
	Average	Peak	Average	Peak	
High rate Conventional and Sludge Reaeration	400-800	1,000-1,200	20-30	50	12-15
Extended Aeration	200-400	800	20-30	50	12-15

[1] Allowable solids loadings are generally governed by sludge settling characteristics associated with cold weather operations.

* Source: *"Design Manual for Upgrading Existing Wastewater Treatment Facilities"*, EPA Technology Transfer, 1974.

Surface Overflow Rate

Importance of hydraulic loading on sedimentation units.

The surface overflow rate is the parameter commonly used to measure the hydraulic loading on the secondary clarifier. The surface overflow rate is expressed as gallons waste flow per day per square foot of surface area (gpd/sq. ft.). The surface overflow rate is directly related to the clarifier's ability to effectively allow solids to settle. Normally, if the surface overflow rate is within the design range, it can be assumed that the detention time and weir overflow rates are also within the design range. However, consideration should be given to flow distribution which can cause short circuiting of flow through the unit.

The surface overflow rate is determined as shown below:

Example Calculation

A. Data Required
   1. Q, Peak hour wastewater flow, gpd = 4,300,000
   2. Surface area of clarifier, sq. ft. = 4415

B. Determine the surface overflow rate.

$$\text{Surface overflow Rate, gpd/sq. ft.} = \frac{Q}{\text{Surface Area, sq. ft.}}$$

$$= \frac{4,300,000}{4415}$$

$$= 974$$

Solids Loading Rate

Excessive solids loadings may contribute to wash out problems.

Secondary clarifiers in the activated sludge process must be designed and operated not only for the surface overflow rates but also for solids loading rates. This is due mainly for settling and compaction of the MLSS which enters the clarifier. When excessive MLSS concentrations are maintained in the process, the ability of the clarifier to compact the solids becomes the governing factor. Therefore solids loading rates on the clarifier become more critical, especially during sudden changes in flow rates which result in clarifier solids wash out. For this reason, the operator should periodically check the solids loading rate on the clarifier.

The solids loading rate is determined as shown below:

DO above 1.0 mg/l

Example Calculation

A. Data Required
1. Q, Peak hour wastewater flow, mgd = 4.3
2. Q_{RAS}, RAS flow rate, mgd = 1.3
3. MLSS concentration, mg/l = 2900
4. Surface area of clarifier, sq. ft. = 4415

B. Determine solids loading rate.

$$\text{lbs solids/day/sq. ft.} = \frac{(Q + Q_{RAS})\,(\text{MLSS})\,(8.34\ \text{lbs/gal})}{\text{Surface Area, sq. ft.}}$$

$$= \frac{(4.3 + 1.3)\,(2900)\,(8.34)}{4415}$$

$$= \frac{104{,}000}{4415}$$

$$= 23.5$$

2.04 PROCESS CONTROL

Select operating parameters for best performance with least cost.

Control of the activated sludge process consist of reviewing operating data and lab test results to select the proper operational parameters (such as F/M, MCRT, Gould Sludge Age, MLSS concentrations, and sludge quality in relation to RAS and WAS control rates) that provide the best performance at the least cost. The plant operator must be both cost-conscious and concerned with the conservation of power as well as the production of an effluent that will meet discharge requirements. For example, to conserve power and minimize operational costs, the operator should select and utilize the control parameters which will provide the required performance so as not to reduce the quality of activated sludge and subsequently the quality of secondary effluent.

Aeration and D.O. Control

Proper D.O. levels.

The D.O. concentration in the aeration tank should normally be maintained between 1.0 and 3.0 mg/l. It is believed that a D.O. concentration greater than 1.0 mg/l should be maintained in the aeration tank at all times to get adequate mixing and microorganism activity. If nitrification is required and the D.O. concentration is allowed to drop below 1.0 mg/l, nitrifying microorganisms will become less active and may possible die off. Conversely, overaeration may result in the breakup of the MLSS floc particles which will appear on the secondary clarifier surface.

Frequency of D.O. monitoring.

It is very important that the operator monitor the aeration tank D.O. levels and air flow rates periodically (every 2 hours is suggested) to make appropriate air rate adjustments as required. If D.O. monitoring instrumentation is provided, it is imperative that it be properly maintained and calibrated to provide values that are valid and reliable.

Effect of excessive air rates.

Since the power costs for operating the activated sludge process are high, excessive air rates are not only wasteful but also expensive and may result in poor sludge settling characteristics in the secondary clarifiers.

The concentration of D.O. in the mixed liquor must be sufficient to ensure that oxygen is available for the microorganisms. When oxygen limits the growth of the microorganisms, the settleability and quality of the activated sludge may be poor. Poor sludge settling has been associated with D.O. concentrations below 0.5 mg/l in the aeration basin. Procedures for monitoring and maintaining aeration and D.O. control are presented in Table II-6 The operator may develop detailed standard operating procedures (SOP) for his plant by utilizing this table.

Return Activated Sludge Control

Need well settling MLSS to return to the mixed liquor.

To properly operate the activated sludge process, a good settling mixed liquor must be achieved and maintained. The MLSS are settled in a clarifier, and then returned to the aeration tank as the Return Activated Sludge (RAS). The RAS makes it possible for the microorganisms to be in the treatment system longer than the flowing wastewater. For conventional activated sludge operations, the RAS flow is generally about 20 to 40 percent of the incoming wastewater flow. Changes in the activated sludge quality will require different RAS flow rates due to settling characteristics of the sludge. Table II-7 shows typical ranges of RAS flow rates for some activated sludge process variations.

TABLE II-7

A GUIDE TO TYPICAL RAS FLOW RATE PERCENTAGES

(Ref: Recommended Standards for Sewage Works, p. 82)

	RAS flow rate as % of incoming wastewater flow to aeration tank		
Type of Activated Sludge Process	Average	Lower Limit	Upper Limit
Conventional	30	15	75
Modified or "high rate"	20	10	50
Step feed	50	20	75
Contact stabilization	100	50	150
Extended aeration	100	50	200

There are two basic approaches that can be used to control the RAS flow rate. These approaches are based on the following:

Basic concepts for RAS control.

1) Controlling the RAS flow rate independently from the influent flow.
2) Controlling the RAS flow rate as a constant percentage of the influent flow.

TABLE II-6
STANDARD OPERATING PROCEDURES
AERATION AND D.O. CONTROL

PROCEDURE	FREQUENCY	METHOD	RANGE	CONDITION	PROBABLE CAUSE	RESPONSE
CHECK D.O. LEVEL	EVERY 2 HOURS	D.O. METER IODOMETRIC METHOD*	NORMALLY 1 TO 3 mg/l	HIGH	TOO MUCH AERATION	DECREASE AERATION
				SATISFACTORY	———	CONTINUE MONITORING
				LOW	TOO LITTLE AERATION	INCREASE AERATION
CHECK UNIFORMITY OF AERATION PATTERN IN AERATION TANK	DAILY	VISUAL OBSERVATIONS	UNIFORM MIXING & ROLL PATTERN, & AIR BUBBLE DISBURSEMENT	DEAD SPOTS	IMPROPER DISTRIBUTION OF AIR	PERFORM D.O. PROFILES AND BALANCE AIR DISTRIBUTION WITH HEADER VALVES
				UNEVEN ROLL PATTERN	IMPROPER DISTRIBUTION OF AIR	
				LOCALIZED BOILING	DIFFUSER MALFUNCTION	PULL AND CHECK FOR PLUGGED DIFFUSERS
CHECK AIR REQUIREMENT (DIFFUSED AERATION)	DAILY	CALCULATION SCF/LB COD OR LB BOD REMOVED	SEE TABLE II-2	HIGH	POOR O_2 TRANSFER OR NITRIFICATION	CHECK UNIFORMITY OF AERATION CHECK FOR NITRIFICATION
				SATISFACTORY	———	CONTINUE MONITORING
				LOW	INACCURATE D.O., COD, OR BOD MEASUREMENT	RECALIBRATE D.O. METER CHECK LAB ANALYSIS
CHECK AIR REQUIREMENT (MECHANICAL AERATION)	MONTHLY	CALCULATION LBS O_2/LB COD OR LB BOD REMOVED	SEE TABLE II-2	HIGH	LOW LOADING	REDUCE NUMBER OF UNITS IN OPERATION--CHECK FOR ADEQUATE MIXING.
				SATISFACTORY	———	
				LOW	HIGH LOADING, INSUFFICIENT AERATION CAPACITY	IMPROVE PRIMARY TREATMENT INCREASE NUMBER OF UNITS IN OPERATION

*COPPER SULFATE-SULFAMIC ACID FLOCCULATION MODIFICATION

Constant RAS Flow Rate Control

Effect of constant RAS on MLSS.

Effect of constant RAS on sludge blanket depth.

Setting the RAS at a constant flow rate that is independent of the aeration tank influent wastewater flow rate results in a continuously varying MLSS concentration will be at a minimum during peak influent flows and a maximum during minimum influent flows. This occurs because the MLSS are flowing into the clarifier at a higher rate during peak flow when they are being removed at a constant rate. Similarly, at minimum influent flow rates, the MLSS are being returned to the aeration tank at a higher rate than they are flowing into the clarifier. The aeration tank and the secondary clarifier *must* be looked at as a system where the MLSS are stored in the aeration tank during minimum wastewater flow and then transferred to the clarifier as the wastewater flows initially increase. In essence, the clarifier acts as a storage reservoir for the MLSS, and the clarifier has a constantly changing depth of sludge blanket as the MLSS moves from the aeration tank to the clarifier and vice versa. The advantage of using this approach is simplicity, because it minimizes the amount of effort for control. It is also especially advantageous for small plants because of limited flexibility.

Constant Percentage RAS Flow Rate Control

Constant % more complex.

Effect of flow proportional RAS control on MLSS.

The second approach to controlling RAS flow rate requires a programmed method for maintaining a constant percentage of the aeration tank influent wastewater flow rate. The program may consist of an automatic flow measurement device, a programmed system, or frequent manual adjustments. The programmed method is designed to keep the MLSS more constant through high and low flow periods.

Comparison of Both RAS Control Approaches

Constant RAS advantages.

The advantages of the constant RAS flow approach are the following:

1) Simplicity.
2) Maximum solids loading on the clarifier occurs at the initial start of peak flow periods.
3) Requires less operational time.

Constant percentage RAS advantages.

The advantages of the constant percentage RAS flow are the following:

1) Variations in the MLSS concentration are reduced and the F/M varies less.
2) The MLSS will remain in the clarifier for shorter time periods, which may reduce the possibility of denitrification in the clarifier.

Disadvantage.

A disadvantage of using the constant flow approach is that the F/M is constantly changing. The range of F/M fluctuation due to the effect of short term variation in the MLSS (because of hydraulic loading) is generally small enough that no significant problems arise due to using the constant flow approach.

Disadvantage of flow proportional RAS control.

The most significant disadvantage of the second approach is that the clarifier is subjected to maximum solids loading when the clarifier contains the maximum amount of sludge. This may result in solids washout with the effluent.

TABLE II-8
STANDARD OPERATING PROCEDURES
RAS CONTROL

PROCESS	CONTROL METHOD	MODE OF OPERATION	WHAT TO CHECK	FREQUENCY OF ADJUSTMENT	WHEN TO CHECK	CONDITION	PROBABLE CAUSE	RESPONSE
COMPLETE MIX OR PLUG FLOW	CONSTANT FLOW	MANUAL	SLUDGE BLANKET	DAILY	EVERY 8 HOURS	HIGH	LOW RAS RATE	INCREASE RETURN
						SATISFACTORY	——	CONTINUE MONITORING
						LOW	HIGH RAS RATE	DECREASE RETURN
	CONSTANT % OF INFLUENT FLOW	MANUAL	% OF INFLUENT FLOW	2 HRS	EVERY 2 HRS	HIGH SATISFACTORY LOW	VARIATIONS IN DAILY INFLUENT FLOW	ADJUST TO DESIRED % OF INFLUENT FLOW
			SLUDGE BLANKET	DAILY	EVERY 8 HRS	HIGH	% OF FLOW TOO LOW	INCREASE % OF FLOW
						SATISFACTORY	——	CONTINUE MONITORING
						LOW	% OF FLOW TOO HIGH	DECREASE % OF FLOW
	CONSTANT % OF INFLUENT FLOW	AUTOMATIC	SLUDGE BLANKET	DAILY	EVERY 8 HRS	HIGH	% OF FLOW TOO LOW	INCREASE % OF FLOW
						SATISFACTORY	——	CONTINUE MONITORING
						LOW	% OF FLOW TOO HIGH	DECREASE % OF FLOW
	CONTROL BY SLUDGE BLANKET LEVEL	AUTOMATIC	SLUDGE BLANKET	DAILY	EVERY 8 HRS	HIGH OR LOW	CONTROLLER MALFUNCTION	FIX CONTROLLER OR MANUALLY ADJUST ACCORDINGLY
						SATISFACTORY	——	CONTINUE MONITORING
REAERATION	CONSTANT % OF FLOW	AUTOMATIC	RATIO OF MLSS/RAS_{SS} (CENTRIFUGE TEST)	EVERY 2 HRS	EVERY 2 HRS	HIGH RATIO	RETURN TOO HIGH	DECREASE RETURN
						SATISFACTORY	——	CONTINUE MONITORING
						LOW RATIO	RETURN TOO LOW	INCREASE RETURN

Smaller plants benefit from constant RAS.

In general, it appears that most activated sludge operations perform well and require less attention when the constant RAS flow rate approach is used. Activated sludge plants with flows of 10 mgd or less are often subject to large hydraulic surges, and performance of these plants will benefit the most from the use of this approach.

How to develop standard operating procedures.

Procedures for monitoring and maintaining RAS flow rates are presented in Table II-8. The operator may develop detailed standard operating procedures (SOP) for his plant by utilizing this table.

Methods of RAS Flow Rate Control

Common approaches for RAS control.

For either RAS flow rate control approaches discussed above, there are a number of techniques which may be used to set the rate of sludge return flow. The most commonly used techniques are listed below:

1) Monitoring the depth of the sludge blanket.
2) Mass balance approach.
3) Settleability approach.
4) SVI approach.

Sludge Blanket Depth

The best method-measure blanket depth in clarifier.

Monitoring the depth of the sludge blanket in the clarifier is the most direct method available for determining the RAS flow rate. The sludge blanket depth and uniformity may be checked routinely by the methods described in Section IV, "LABORATORY CONTROL." The blanket depth should be kept to less than one-fourth of the clarifier sidewall water depth. The operator must check the blanket depth on a routine basis, making adjustments in the RAS to control the blanket depth.

Increasing blanket-solution on Short Term is to increase RAS but Long Term is to decrease solids inventory by wasting.

If it is observed that the depth of the sludge blanket is increasing, however, an increase in the RAS flow can only solve the problem on a short term basis. Increases in sludge blanket depth may result from having too much activated sludge in the treatment system, and/or because of a poorly settling sludge. Long-term corrections must be made that will improve the settling characteristics of the sludge or remove the excess solids from the treatment system. If the sludge is settling poorly, increasing the RAS flow may even cause more problems by further increasing the flow through the clarifier. If the sludge is settling poorly due to bulking, the environmental conditions for the microorganisms must be improved. If there is too much activated sludge in the treatment system, the excess sludge must be wasted.

Measurements same time each day - during maximum flow.

Measurements of the sludge blanket depth in the clarifier should be made at the same time each day. The best time to make these measurements is during the period of maximum daily flow, because the clarifier is operating under the highest solids loading rate. The sludge blanket should be measured daily, and adjustments to the RAS rate can be made as necessary. Adjustments in the RAS flow rate should only be needed occasionally if the activated sludge process is operating properly.

Blanket depth points out sludge collection system malfunctions.

An additional advantage of monitoring the sludge blanket depth is that problems, such as improperly operating sludge collection equipment, will be observed due to irregularities in the blanket depth. A plugged pickup on a clarifier sludge collection system would cause sludge depth to increase in the area of the pickup, and decrease in the areas where the properly operating pickups are located. These irregularities in sludge blanket depth are easily monitored by measuring profiles of blanket depth across the clarifier with the methods and equipment discussed in Section IV, "LABORATORY CONTROL."

Mass Balance Approach

Constant blanket level.

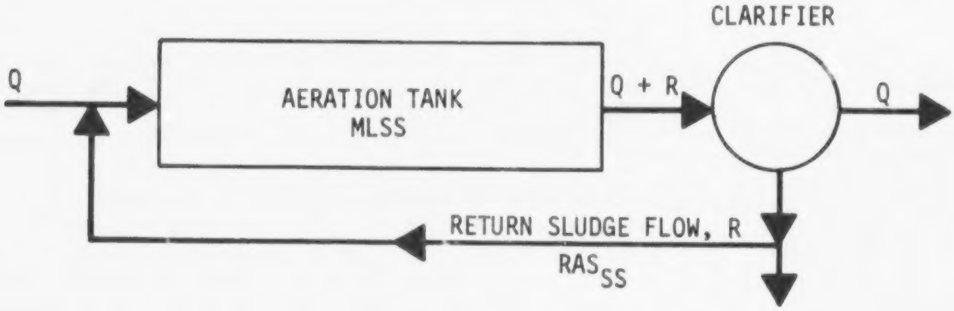
The mass balance approach is a useful tool for calculating the RAS flow rate; however, it does assume that the level of the sludge blanket in the clarifier is constant.

Can estimate RAS flow from MLVSS/RAS ratio.

A side benefit of the mass balance approach to RAS flow rate control is that in plants without functioning RAS flow meters, the RAS flow can be estimated from the measured MLSS to RAS_{SS} concentration relationships.

Basis of a mass balance.

The calculations used in this approach are based on a mass balance performed on the suspended matter in the activated sludge process. A mass balance is performed by accounting for all of the suspended matter that enter and leave the process. A typical mass balance around an aeration tank is shown in Figure II-3.



AERATION TANK MASS BALANCE

FIGURE II-3

Example Calculation

A. Data Required
   1. Q, influent wastewater flow, mgd = 7.5
   2. MLSS concentration, mg/l = 2000
   3. RAS_{SS} Return Sludge concentration, mg/l = 7500

B. Determine RAS flow rate based on MLSS to RAS ratio.

$$Q_{RAS}\text{, mgd} = \frac{Q \times MLSS}{RAS_{SS} - MLSS}$$

$$= \frac{7.5 \times 2000}{7500 - 2000}$$

$$= \frac{15{,}000}{5500}$$

$$= 2.7 \text{ or}$$

$$= \frac{2.7}{7.5} \times 100 = 32\% \text{ of influent flow rate}$$

Settleability Approach

What is sludge settleability?

Another method of calculating the RAS flow rate is based on the result of the 30-minute settling test. Settleability is defined as the percentage of volume occupied by the sludge after settling for 30 minutes.

How is it determined?

If after 30 minutes of settling, the final sludge volume were 275 ml in a one liter graduate, the RAS flow rate would be calculated as follows:

Example Calculation

A. Data Required
   1. Q, influent wastewater flow, mgd = 7.5
   2. SV, sludge settling volume in 30 minutes, ml/l = 275

B. Determine RAS flow rate based on 30-minute sludge settleability test.

$$Q_{RAS}, \text{mgd} = \frac{SV}{1000 - SV} \times 100$$

$$= \frac{275}{1000 - 275} \times 100$$

$$= \frac{275}{725} \times 100$$

$$= 37.9 \text{ or } 38\% \text{ of influent flow rate}$$

Thus,

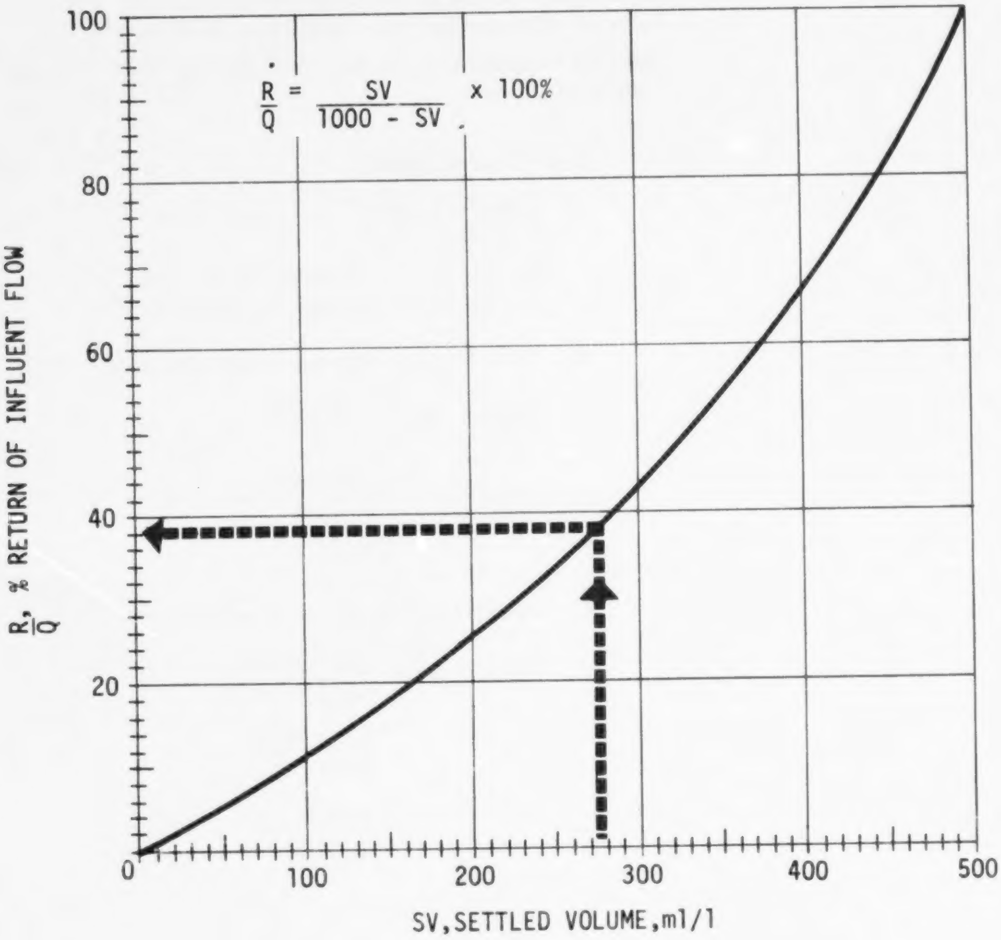
$$Q_{RAS}, \text{mgd} = .38 \times 7.5$$

$$= 2.8$$

Figure II—4 can be used to calculate the RAS flow as a percentage of the influent flow. All the operator does is determine the SV ml/l at 30-minutes and then read the R/Q off of the vertical axis. To calculate the Q_{RAS}, multiply the R/Q term by Q.

Limited value.

The settleability method is somewhat less accurate than the solids balance approach, as it suffers from the assumption that measurements made with a laboratory settling cylinder will model the settling in a clarifier. This assumption will seldom (if ever) be true because of the effects of the cylinder walls and the quiescent nature of the liquid in the cylinder. Some operators have found that gently stirring (1-2 rpm) the sludge during the settling test reduces these problems.



ESTIMATING RETURN FROM SETTLEABILITY TEST

FIGURE II-4

SVI Approach

To determine the RAS flow rate using the Sludge Volume Index (SVI), it is necessary to combine the mass balance and settleability approach. This method is subject to the same limitations as the settleability method.

This method is based on using the SVI to estimate the suspended solids concentration in the RAS. This value for RAS_{SS} is then used in a mass balance to determine the RAS flow rate. The RAS flow rate may be determined as follows:

Example Calculation

A. Data Required
   1. SVI = 120
   2. Q, Influent Wastewater flow, mgd = 7.5
   3. MLSS concentration, mg/l = 2000

B. Determine RAS_{SS} concentration based on SVI.

$$RAS_{SS}\text{, mg/l} = \frac{1{,}000{,}000}{SVI} = \frac{1{,}000{,}000}{120} = 8333$$

C. Determine RAS flow rate based on SVI

$$Q_{RAS}\text{, mgd} = \frac{Q \times MLSS}{RAS_{SS} - MLSS} = \frac{7.5 \times 2000}{8333 - 2000} = \frac{15{,}000}{6333} = 2.4 \text{ or}$$

$$= \frac{2.4}{7.5} \times 100 = 32\% \text{ of influent flow rate}$$

NOTE: The SVI value was chosen to make the calculated RAS flows similar to those calculated in the previous examples.

Value of SVI is a process stability indicator — Not for RAS calculations.

The real value in the SVI is not in calculating the RAS flow, but in its use as a process stability indicator. Changes in the SVI at constant MLSS are more important than the SVI value. Never be concerned about comparing the SVI of different treatment plants, because the SVI value that indicates good operation in one plant may not necessarily apply to good operation in other plants.

Return Rates with Separate Sludge Reaeration

RAS rates are more significant with separate sludge reaeration.

In the sludge reaeration variation of the activated sludge process, the return sludge rate is much more significant. This is true because the rate of return directly affects the ratio of sludge concentration between the contact portion of the process and the stabilization or reaeration portion. Refer to Activated Sludge with Sludge Reaeration in Section III, "FUNDAMENTALS", for more information. Consideration of the ratio of sludge concentration between these two portions must be coordinated with the mass balance control method of setting the return rates. Generally, a higher rate of return will shift solids from the stabilization portion of the process to the contact portion of the process. Adequate theory for making rational adjustments of the contact/stabilization ratio are just becoming available, and, at this point, the operator must depend on crude rules of thumb or on his own operating experience to determine which levels are appropriate. These rules of thumb include the following:

- The SS concentration in the reaeration portion will eventually equal the RAS_{SS}. Therefore, the RAS flow rate should be controlled on the basis of maintaining the desired SS concentration in the reaeration portion of the process.
- The contact portion SS concentration may be determined by the following formula:

$$\text{Contact MLSS, mg/l} = \frac{(Q_{RAS})(RAS_{SS}, \text{mg/l})}{Q + Q_{RAS}}$$

- Q_{RAS} may be determined by the following formula:

$$Q_{RAS} = \frac{(Q)(\text{MLSS, mg/l})}{RAS_{SS}, \text{mg/l} - \text{MLSS, mg/l}}$$

- If the SVI remains constant or begins to drop, it indicates that the solids inventory in the process may be to high and wasting should be increased. If the SVI increases in conjunction with a rising sludge blanket in the clarifier, sludge bulking may occur. Sludge wasting should be increased.

Waste Activated Sludge Control

Activated sludge is controlled by WAS.

The activated sludge process is basically controlled by the amount of activated sludge that is wasted. The amount of waste activated sludge (WAS) removed from the process effects all the following:

- Effluent quality
- The growth rate of the microorganism
- Oxygen consumption
- Mixed liquor settleability
- Nutrient quantities needed
- The occurrence of foaming/frothing
- The possibility of nitrifying

WAS is used to maintain a desired growth rate.

Attempt to maintain steady-state.

The objective of wasting activated sludge is to maintain a balance between the microorganisms and the amount of food such as COD and BOD. It is known that when the microorganisms remove BOD from wastewater, the amount of activated sludge increases (microorganisms grow and multiply). The rate at which these microorganisms grow is called the growth rate and is defined as the increase in the amount of activated sludge that takes place in one day. The objective of sludge wasting is to remove just that amount of microorganisms that grow. When this is done the amount of activated sludge formed by the microorganism growth is just balanced by that which is removed from the process. This therefore allows the total amount of activated sludge in the process to remain somewhat constant. This condition is called "steady-state" which is a desirable condition for operation. However, "steady-state" can only be approximated because of the variations in the nature and quantity of the food supply (BOD) and of the microorganism population. It is the objective of process control to approach a particular "steady-state" by controlling any one or a combination of the following control parameters:

- MCRT
- F/M
- Gould Sludge Age
- Volatile solids inventory
- MLVSS concentration
- Sludge Quality Control

The best mode of process control will produce a high quality effluent with consistent treatment at a minimal cost.

WAS is normally a portion of RAS.

Wasting of the activated sludge is normally done by removing a portion of the RAS flow. The waste activated sludge is either pumped to thickening facilities and then to a digester, or to the primary clarifiers where it is pumped to a digester with the raw sludge. Procedures for making WAS adjustments are presented in Table II-9 which the operator may use to develop an SOP.

Alternate for wasting sludge.

An alternate method for wasting sludge is from the mixed liquor in the aeration tank. There is much higher concentration of suspended matter in the RAS than there is in the mixed liquor. Therefore, when wasting is practiced from the mixed liquor larger sludge handling facilities are required. Wasting from the RAS takes advantage of the gravity settling and thickening of the sludge that occurs in the secondary clarifier. However, wasting from the mixed liquor has the advantage of not wasting excessive amounts of sludge because of the large quantity of sludge involved. The extra security of wasting from the mixed liquor should not be underestimated. Unfortunately, many plants do not have the flexibility to waste from the mixed liquor nor are there sufficient sludge handling facilities to handle the more dilute sludge.

Methods of Sludge Wasting

Wasting on intermittent or continuous basis.

Wasting of the activated sludge can be done on an intermittent or contino us basis. The intermittent wasting of sludge means that wasting is conducted on a batch basis from day to day.

TABLE II-9
STANDARD OPERATING PROCEDURES FOR WAS CONTROL

METHOD OF CONTROL	PROCESS OPERATION	WHAT TO CHECK	WHEN TO CHECK	CALCULATIONS	FREQUENCY OF ADJUSTMENT	CONDITIONS	PROBABLE CAUSE	RESPONSE*
CONSTANT F/M	HIGH RATE	MLVSS & INFLUENT COD	DAILY	F/M BASED ON – $\frac{\text{5 DAY AVG. COD}}{\text{5 DAY AVG. MLVSS}}$	DAILY	ACTUAL F/M: HIGH	EXCESSIVE WASTING	REDUCE WAS
	CONVENTIONAL RATE					SATISFACTORY	——	
	EXTENDED AERATION					LOW	INSUFFICIENT WASTING	INCREASE WAS
CONSTANT MLVSS	HIGH RATE	MLVSS & INFLUENT COD OR BOD	DAILY	VOLATILE SOLIDS INVENTORY	DAILY	ACTUAL MLVSS: HIGH	INSUFFICIENT WASTING	INCREASE WAS
	CONVENTIONAL RATE					SATISFACTORY	——	
	EXTENDED AERATION					LOW	EXCESSIVE WASTING	REDUCE WAS
CONSTANT MCRT	HIGH RATE	MLSS, WAS_{SS}, Q_{WAS}, & $EFFL_{SS}$	DAILY	5 DAY AVG SOLIDS INVENTORY	DAILY	ACTUAL MCRT: HIGH	INSUFFICIENT WASTING	INCREASE WAS
	CONVENTIONAL RATE			5 DAY AVERAGE OF SOLIDS IN WAS		SATISFACTORY	——	
	EXTENDED AERATION			5 DAY AVERAGE OF SOLIDS IN EFFLUENT		LOW	EXCESSIVE WASTING	REDUCE WAS
CONSTANT GOULD SLUDGE AGE	HIGH RATE	INFLUENT SS, & MLSS	DAILY	5 DAY AVG OF SS INVENTORY & SS IN INFLUENT	DAILY	ACTUAL GSA: HIGH	INSUFFICIENT WASTING	INCREASE WAS
	CONVENTIONAL RATE					SATISFACTORY	——	
	EXTENDED AERATION					LOW	EXCESSIVE WASTING	REDUCE WAS

*Response - Calculations should be made to determine the WAS rate. However, when increasing or decreasing daily WAS rates, any changes should not exceed 10 to 15 percent of the previous day's WAS rate. This is necessary to allow the process to stabilize.

If wasting is done from the RAS, the operator must measure the volatile suspended matter in the RAS to obtain average concentrations. If the volatile content in the RAS concentration is decreasing, the WAS flow rate must be increased proportionally to waste the proper amount of VSS. Similarly, if there is an increase in the RAS volatile content, the WAS flow rate must be decreased proportionally.

When continuous wasting is practiced, the operator should check the RAS_{VSS} at least once every shift and make the appropriate Q_{WAS} adjustment.

How to calculate daily Q_{WAS} adjustments.

Example Calculation

A. Data Required
  1. Q_{WAS}, Current waste sludge flow rate, mgd = 0.05
  2. RAS_{VSS1} Concentration first day, mg/l = 6000
  3. RAS_{VSS2} Concentration second day, mg/l = 7500

B. Determine the adjusted WAS flow rate based on RAS_{VSS} increase from 6000 to 7500 mg/l.

$$Q_{WAS}\text{, mgd adjusted} = \frac{RAS_{VSS1}}{RAS_{VSS2}} \times Q_{WAS}$$

$$= \frac{6000}{7500} \times 0.05$$

$$= 0.80 \times 0.05$$

$$= 0.04$$

When intermittent wasting is practiced the operator must check the RAS_{VSS} to calculate the necessary Q_{WAS}. In addition this calculation must be readjusted for the reduced time of wasting.

How to calculate Q_{WAS} for intermittent wasting.

Example Calculation

A. Data Required
  1. Q_{WAS}, adjusted from above, mgd = 0.04
  2. P, Selected wasting period, hrs/day = 4

B. Determine the WAS flow rate for the four hour wasting period.

$$Q_{WAS}\text{, mgd @ 4 hours} = \frac{24\text{ hrs/day}}{P_1\text{ hrs/day}} \times Q_{WAS}\text{, adjusted}$$

$$= \frac{24}{4} \times 0.04$$

$$= 6 \times 0.04$$

$$= 0.24$$

The operator would repeat the Q_{WAS} calculation for each wasting period to take into account the RAS_{VSS} variations.

Less variation in the SS during the wasting period with intermittent wasting.

Intermittent wasting of sludge has the advantage that less variation in the suspended matter concentration will occur during the wasting period, and the amount of sludge wasted will be more accurately known. The disadvantages of intermitttent wasting are that the sludge handling facilities in the treated plant may be loaded at a higher hydraulic loading rate and that the activated sludge process is out of balance for a period of time until the microorganisms regrow to replace those wasted over the shorter period of time.

Must allow for SS in the effluent.

Especially important if high effluent SS.

In using either of these methods for wasting, the operator does not have complete control of the amount of activated sludge wasted due to the solids lost in the effluent. This "wasting" of activated sludge in the effluent must be accounted for with any method of process control or the system will always be slightly out of balance. The loss of activated sludge in the effluent generally accounts for less than five percent of the total solids that need to be wasted; however, it is necessary to be aware of this loss and to be able to take it into account by the methods shown in the constant MCRT control section. The need for taking into account the solids lost in the effluent is especially important if one encounters situations where large concentrations of SS are washed out in the secondary effluent.

Five techniques of control.

Proper control of the WAS will produce a high quality effluent with minimum operational difficulties. There are five techniques that are commonly used for controlling the WAS. These techniques are listed below in the order of their frequency of use in this country.

Frequency of Use*

1. Constant MLVSS Control
2. Constant Gould Sludge Age Control
3. Constant F/M Control
4. Constant MCRT Control
5. Sludge Quality Control

*Developed on the basis of those treatment plants which were visited during development of the manual.

Constant MLVSS Control

This technique for process control is used by many operators because it is simple to understand and involves a minimum amount of laboratory control. The MLVSS control technique usually produces good quality effluent as long as the incoming wastewater characteristics are fairly constant with minimal variations in influent flow rates.

With this technique, the operator tries to maintain a constant MLVSS concentration in the aeration tank to treat the incoming wastewater organic load. To put it in simple terms, if it is found that a MLVSS concentration of 2000 mg/l produces a good quality effluent, the operator must waste sludge from the process to maintain that concentration. If the MLVSS level increases above the desired concentration, more sludge is wasted until the desired level is reached again.

The laboratory control tests and operational data involved in using this technique include the following:

- MLVSS concentration
- RAS VSS concentration
- Influent wastewater flow rate
- Volume of aeration tank

Whether a new plant is being started or the operation of an existing plant is being checked, this control technique is used to indicate when activated sludge should be wasted. In most cases it is not the most reliable technique because it ignores process variables such as F/M and microorganism growth rate necessary for maintaining optimum system balance. When operational problems occur the operator is unable to make rational process adjustments due to the lack of process control data.

The control technique is implemented by choosing an MLVSS concentration which produces the highest quality effluent while maintaining a stable and economical operation. WAS flow rates are determined as follows:

Example Calculation

A. Data Required

*1. SI_1, Desired solids inventory in aeration tank, lbs = 20,016

*2. SI_2, Current solids inventory in aeration tank, lbs = 21,716

3. RAS concentration, mg/l = 6200

B. Determine sludge to be wasted per day from RAS system.

$$Q_{WAS}, \text{mgd} = \frac{SI_2 - SI_1}{\text{RAS} \times 8.34 \text{ lbs/gal}}$$

$$= \frac{21{,}716 - 20{,}016}{6200 \times 8.34}$$

$$= \frac{1700}{51{,}708}$$

$$= .032$$

*Refer to Section 2.03 for solids inventory calculations in aeration tank.

Constant Gould Sludge Age Control

The concept of sludge age is based on the ratio of the lbs/day of influent wastewater suspended matter to the solids inventory in the aeration tank. Gould first developed the sludge age for use in the Tallmans Island Treatment Plant in New York City. Thus, sludge age is also known as the Gould Sludge Age (GSA) and it should not be confused with the MCRT. The GSA is based on the assumption that the ratio between the BOD and suspended matter is fairly constant in the wastewater. Difficulties are commonly experienced using the GSA control technique when the BOD to solids ratio in the wastewater changes. The GSA ranges from 3 to 8 days in most activated sludge plants. The control technique is accomplished by wasting sludge to maintain a constant GSA which produces the best effluent quality. It is determined as follows:

Example Calculation

A. Data Required
   1. Influent wastewater or primary effluent suspended matter concentration, mg/l = 100
   2. Q, Influent or primary effluent flow rate, mgd = 7.5
   *3. SI, solids inventory in aeration tank, lbs = 20,016

B. Determine Gould Sludge Age in days.

$$\text{GSA, days} = \frac{\text{SI}}{(\text{pri. effl. mg/l})\,(\text{Q mg/l})\,(8.34\ \text{lbs/gal})}$$

$$= \frac{20{,}016}{(100)\,(7.5)\,(8.34)}$$

$$= \frac{20{,}016}{6255}$$

$$= 3.2$$

WAS flow rate using the GSA control technique is determined as follows:

Example Calculation

A. Date Required

1. Desired GSA, day = 5
2. Influent or primary effluent suspended matter, lbs per day (from above calculation) = 6255
*3. SI, Solids inventory in aeration tank, lbs = 33,075
4. RAS_{SS} concentration, mg/l = 6300

B. Determine desired pounds of MLSS to be maintained in aeration tank at a 5 day GSA.

$$\text{MLSS, lbs desired} = \text{GAS} \times \text{Pri. effl., lbs/day}$$

$$= 5 \times 6255$$

$$= 31{,}275$$

C. Determine WAS flow rate to maintain desired GSA.

$$Q_{WAS}\text{, mgd} = \frac{\text{SL -MLSS desired}}{\text{RAS} \times 8.34 \text{ lbs/gal}}$$

$$= \frac{33{,}075 - 31{,}275}{6300 \times 8.34}$$

$$= \frac{1800}{52{,}542}$$

$$= .034$$

*Refer to Section 2.03.

Constant F/M Control

F/M ensures proper organic loading.

Constant F/M control is used to ensure that the activated sludge process is being loaded at a rate that the microorganisms in the MLSS are able to utilize most of the food supply in the wastewater being treated. If too much or too little food is applied for the amount of microorganisms, operating problems may occur and the effluent quality may degrade.

Food measured by COD or BOD.

There are four things that should be remembered about the F/M.

1. The food concentration is estimated with the COD (or BOD) tests. The oxygen demand tests provide crude but reliable approximations of the actual amount of COD removed by the microorganisms.

Food applied.

2. The amount of food applied is important to calculate the F/M.

F/M based on MLVSS and not MLSS.

3. The quantity of microorganisms can be represented by the quantity of MLVSS. Ideally, the living or active microorganisms would simply be counted, but this is not feasible, and studies have shown that the MLVSS is a good approximation of the microorganisms concentrations in the MLSS.

Use five day moving averages to calculate F/M.

4. The data obtained to calculate the F/M should be based on a five day moving average.

The range of organic loading of activated sludge plants is described by the F/M. The three ranges of organic loading are conventional, extended aeration, and high rate. These ranges have been shown to produce activated sludge that settles well.

F/M loading ranges in Table II-10.

Table II-10 presents the ranges of F/M that have been used successfully with the three loading conditions. The F/M values shown are expressed in terms of BOD, COD and Total Organic Carbon, (TOC). The TOC is an additional means of estimating organic loading. The values indicated are guidelines for process control, and they should not be thought of as minimums or maximums.

TABLE II-10

TYPICAL RANGES FOR F/M LOADINGS

	Conventional AS Range F/M	Extended Aeration F/M	High Rate Range F/M
BOD	0.1 to 0.5	0.05 to 0.1	0.5 to 2.5
COD(1)	0.06 to 0.3	0.03 to 0.06	0.3 to 1.5
TOC(2)	0.25 to 1.5	0.1 to 0.25	1.5 to 6.0

(1) Assumes BOD/COD for settled wastewaters = 0.6

(2) Assumes BOD/TOC for settled wastewaters = 2.5

The F/M is calculated from the amount of COD or BOD applied each day and from the solids inventory in the aeration tank. Refer to Section 2.03 for solids inventory calculations.

Example Calculation

How to calculate F/M.

A. Data Required

1. COD or BOD concentration in wastewater applied to the aeration tank, mg/l = 100
2. Q, Influent or primary effluent flow rate, mgd = 7.5
3. SI, Solid inventory in aeration tank, lbs = 21,017

B. Determine the F/M ratio expressed as pounds COD or BOD applied per pound MLVSS.

$$F/M = \frac{(\text{BOD, mg/l})\,(\text{Q, mgd})\,(8.34\ \text{lbs/gal})}{\text{SI}}$$

$$= \frac{(100)\,(7.5)\,(8.34)}{21{,}017}$$

$$= \frac{6255}{21{,}017}$$

$$= 0.297$$

Graphical solution for F/M calculation.

Figures II-5, II-6, II-7 can also be used to calculate the F/M as determined in the above example problem. These figures are for plants having average influent flows of up to 5, 10, and 50 mgd. The following illustration will show how to determine the F/M ratio with these figures. Data from Figure II-6 is used:

Step-by-step.

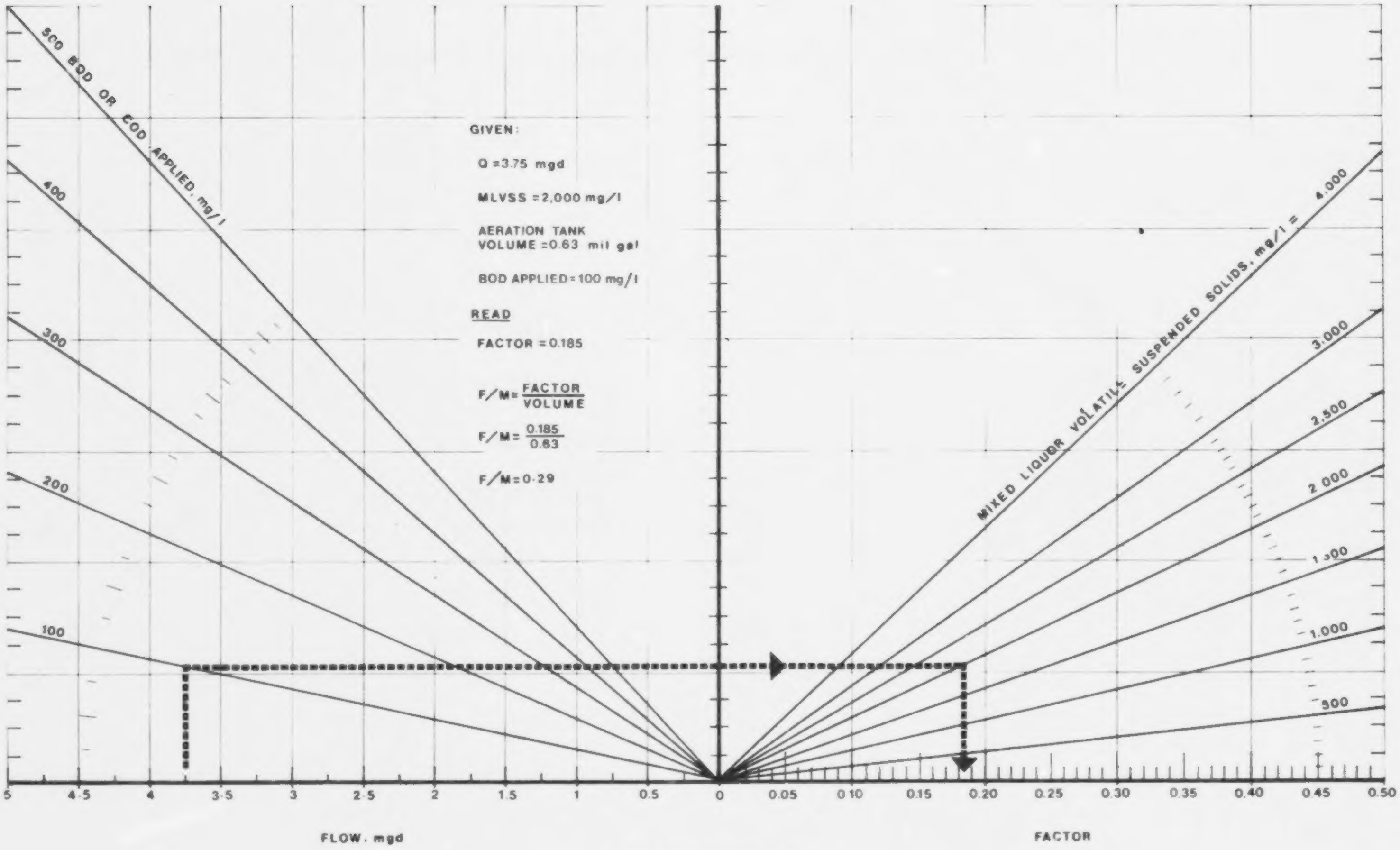
1. Use the figure with a maximum flow range near the flow in your plant. In this case use Figure II-6, which has a maximum flow of 10 mgd, which is the most accurate curve for the flow of 7.5 mgd.
2. Referring to Figure II-6

• Find the flow.	7.5 mgd
• Draw a line vertically to the BOD or COD applied	100 mg/l
• Draw a line parallel to the bottom axis to intersect the MLVSS line	2,000 mg/l
• Draw a line vertically downward to the Factor	0.37
• Divide the factor by the aeration tank volume	1.26 mil gal
• The F/M is equal to:	

$$0.29 = \frac{\text{lbs BOD Applied/day}}{\text{lbs. MLVSS}}$$

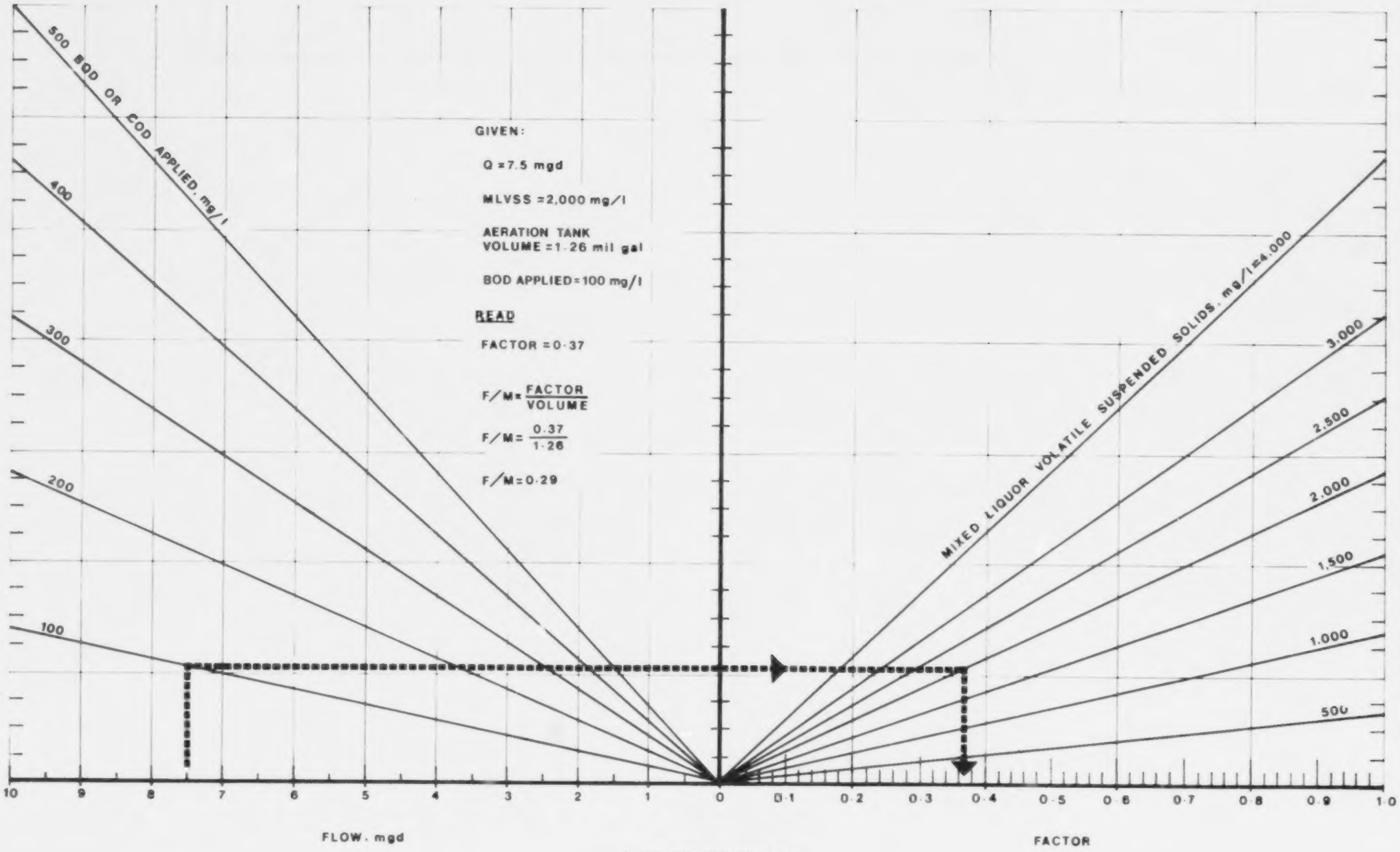
The F/M is essentially equal to the F/M calculated previously. The difference between 0.29 and 0.297 is not significant.

The use of Figures II-5, II-6, II-7 is strongly recommended. The figures can be made to read F/M directly for an individual plant by multiplying the factor by the aeration tank volume and writing a new values in place of the factor. The use of a clear plastic sheet to cover the figure and a crayon like marker will extend the life of a particular sheet. Additional sheets can also be printed from the original.



F/M CALCULATIONS

FIGURE II-5



GIVEN:

Q = 7.5 mgd

MLVSS = 2,000 mg/l

AERATION TANK
VOLUME = 1·26 mil gal

BOD APPLIED = 100 mg/l

READ

FACTOR = 0·37

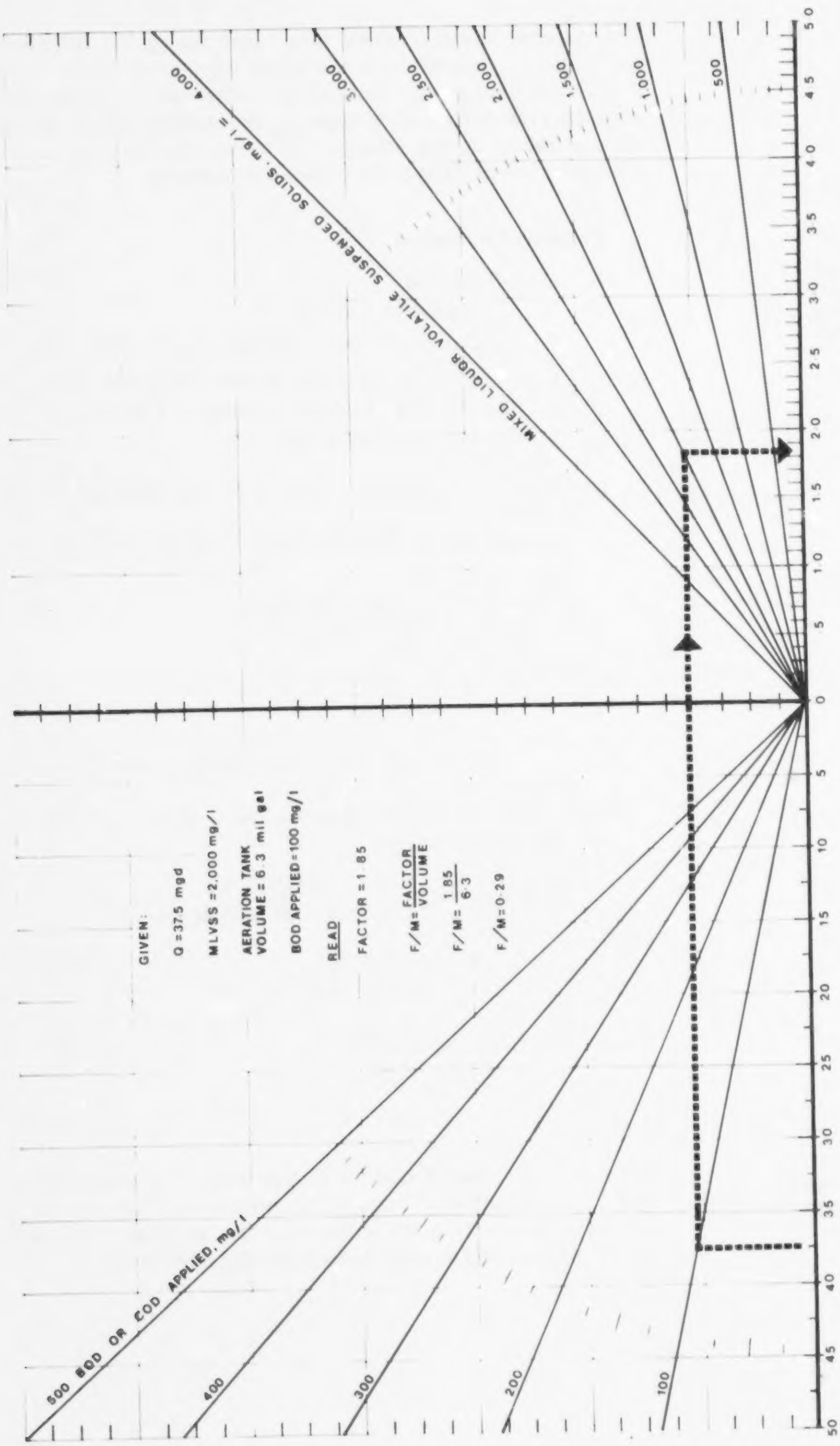
$F/M = \frac{FACTOR}{VOLUME}$

$F/M = \frac{0.37}{1.26}$

$F/M = 0.29$

F/M CALCULATIONS

FIGURE II-6



GIVEN:

Q = 37.5 mgd

MLVSS = 2,000 mg/l

AERATION TANK
VOLUME = 6.3 mil gal

BOD APPLIED = 100 mg/l

READ

FACTOR = 1.85

$F/M = \frac{FACTOR}{VOLUME}$

$F/M = \frac{1.85}{6.3}$

$F/M = 0.29$

F/M CALCULATIONS
FIGURE II-7

The determination of WAS flow rates using the constant F/M control technique is calculated in the same manner as for the constant MLVSS and Gould Sludge Age techniques. However, the solids inventory for the aeration tank can be more logically determined based on the COD or BOD concentration of the wastewater to be treated when using the F/M for process control. This is determined as follows:

How to calculate the MLSS, mg/l needed for the desired F/M.

Example Calculation

A. Date Required

1. Desired F/M = 0.29
2. COD or BOD concentration, mg/l = 100
3. Q, Influent or primary effluent flow rate, mgd = 7.5
4. Q_A, Aeration tank volume mg = 1.26
5. Percent MLVSS = 70

B. Determine pounds of MLVSS for desired F/M.

$$\text{MLVSS, lbs} = \frac{(\text{BOD, mg/l})\,(\text{Q, mgd})\,(8.34\ \text{lbs/gal})}{\text{F/M desired}}$$

$$= \frac{(100)\,(7.5)\,(8.34)}{0.29}$$

$$= \frac{6255}{0.29}$$

$$= 21{,}569 \text{ (equal to approx. 2000 mg/l of MLVSS)}$$

C. Determine MLSS mg/l required in the aeration tank if the MLVSS is 70%.

$$\text{MLSS}_{\text{mg/l}} = \frac{\text{MLVSS, lbs}}{(Q_A)\,(\%\ \text{MLVSS})\,(8.34\ \text{lbs/gal})}$$

$$= \frac{21569}{(1.26)\,(.7)\,(8.34)}$$

$$= \frac{21{,}569}{7.35}$$

$$= 2931$$

F/M control best used with MCRT control.

The F/M control technique for sludge wasting is best used in conjunction with the constant MCRT control technique. Control to a constant MCRT is achieved by wasting an amount of the aeration tank solids inventory which in turn fixes or provides a constant F/M ratio.

Constant MCRT Control

MCRT is used to calculate amount of sludge to be wasted.

Current technology considers MCRT to be the best process control technique available to the plant operator. By using the MCRT, the operator can control the organic loading (F/M). In addition, he can calculate the amount of activated sludge that should be wasted in a logical manner. It is recommended that operators become familiar with the use of constant MCRT control.

Expresses Residence Time of solids.

Basically, the MCRT expresses the average time that a microorganism will spend in the activated sludge process. The MCRT value should be selected to provide the best effluent quality. This value should correspond to the F/M loading for which the process is designed. For example, a process designed to operate at conventional F/M loading rates may not produce a high quality effluent if it is operated at a low MCRT because the F/M may be too high for its design. Therefore the operator must find the best MCRT for his process by relating it to the F/M as well as the effluent COD, BOD and suspended matter concentrations.

MCRT controls type of microorganisms in process.

The MCRT also determines the type of microorganisms that predominate in the activated sludge, because it has a direct influence on the degree of nitrification which may occur in the process. A plant operated at a longer MCRT of 15-20 days will generally produce a nitrified effluent. A plant operating with an MCRT of 5-10 days may not produce a nitrified effluent unless wastewater temperatures are unusually high. Table II-11 presents the typical range of MCRT values that will enable nitrification at various wastewater temperatures. The values shown have been used successfully to produce nitrified effluents at numerous plants.

TABLE II-11

MCRT NEEDED TO PRODUCE A NITRIFIED EFFLUENT AS RELATED TO THE TEMPERATURE

Temperature, °C	MCRT, Days
10	30
15	20
20	15
25	10
30	7

MCRT & temperature can indicate nitrification.

As stated earlier, MCRT expresses the average time that a microorganism spends in the activated sludge process. The MCRT and the WAS flow rate for maintaining a constant MCRT is determined as follows:

How to calculate MCRT and the WAS based on MCRT.

Example Calculation

A. Data Required

1. SI, Solids inventory in aeration tank, lbs = 21,017
2. RAS_{VSS} concentration, mg/l = 7500
3. Q_{WAS}, assumed WAS is from RAS system, mgd = 0.030
4. $Effl_{VSS}$, Effluent volatile suspended matter concentration, mg/1 = 12
5. Q, Plant flow, mgd = 7.5
6. Desired MCRT, days = 7.5

B. Determine MCRT in days.

$$\text{MCRT, days} = \frac{\text{SI}}{[(RAS_{VSS} \times Q_{WAS}) + (effl_{VSS} \times Q)]\ 8.34\ \text{lbs/gal}}$$

$$= \frac{21{,}017}{[(7500 \times 0.03) + (12 \times 7.5)]\ 8.34}$$

$$= \frac{21{,}017}{[225 + 90]\ 8.34}$$

$$= \frac{21{,}017}{315 \times 8.34}$$

$$= \frac{21{,}017}{2627}$$

$$= 8.0$$

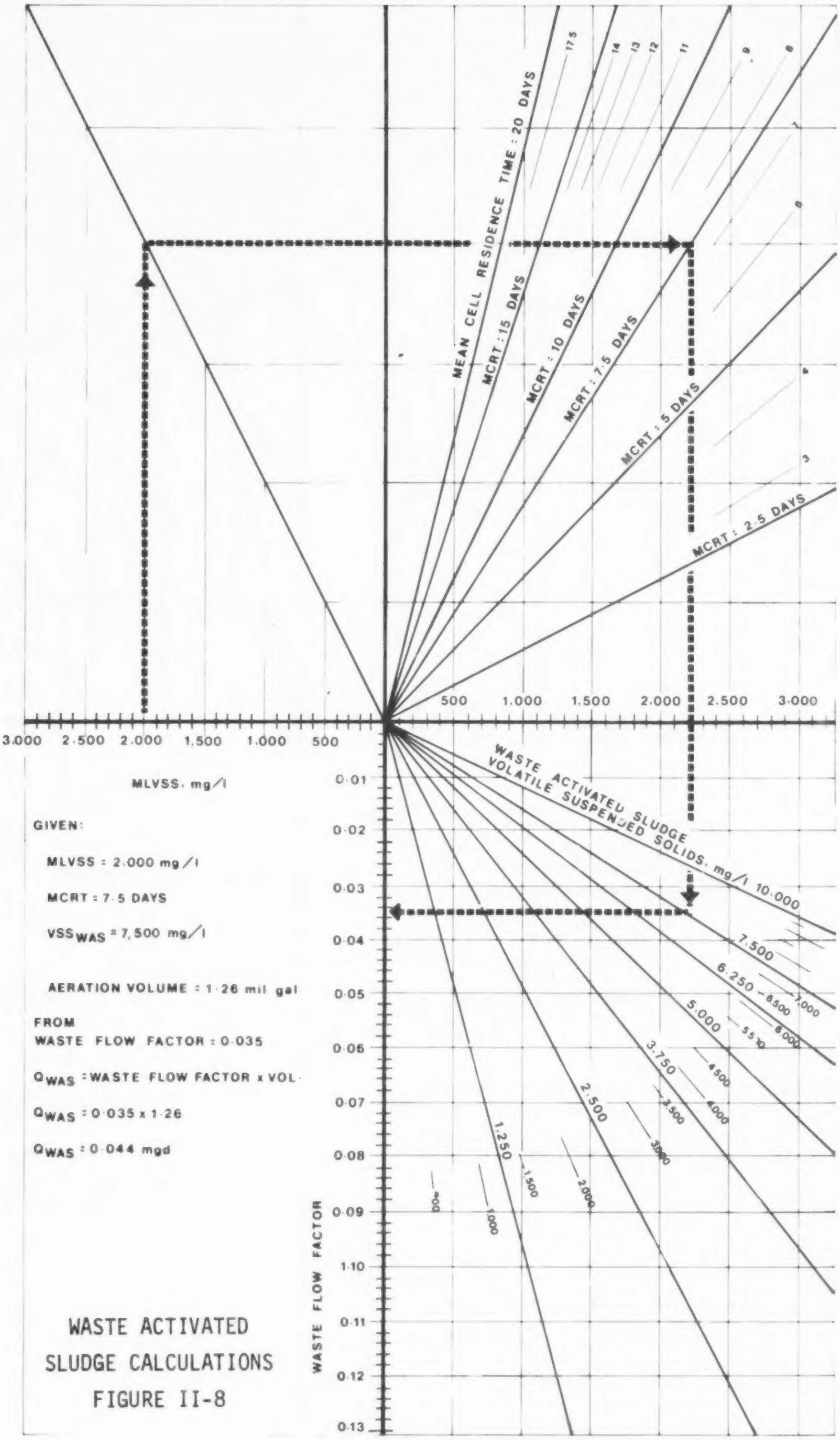
C. Determine WAS flow rate to maintain MCRT of 7.5 days.

$$Q_{WAS}\text{, mgd} = \frac{\text{SI}}{(\text{MCRT desired})\ (RAS_{VSS})\ (8.34\ \text{lbs/gal})}$$

$$= \frac{21{,}017}{(7.5)\ (7500)\ (8.34)}$$

$$= \frac{21{,}017}{469{,}125}$$

$$= 0.045$$



GIVEN:

MLVSS = 2.000 mg/l

MCRT = 7.5 DAYS

VSS_{WAS} = 7,500 mg/l

AERATION VOLUME = 1.26 mil gal

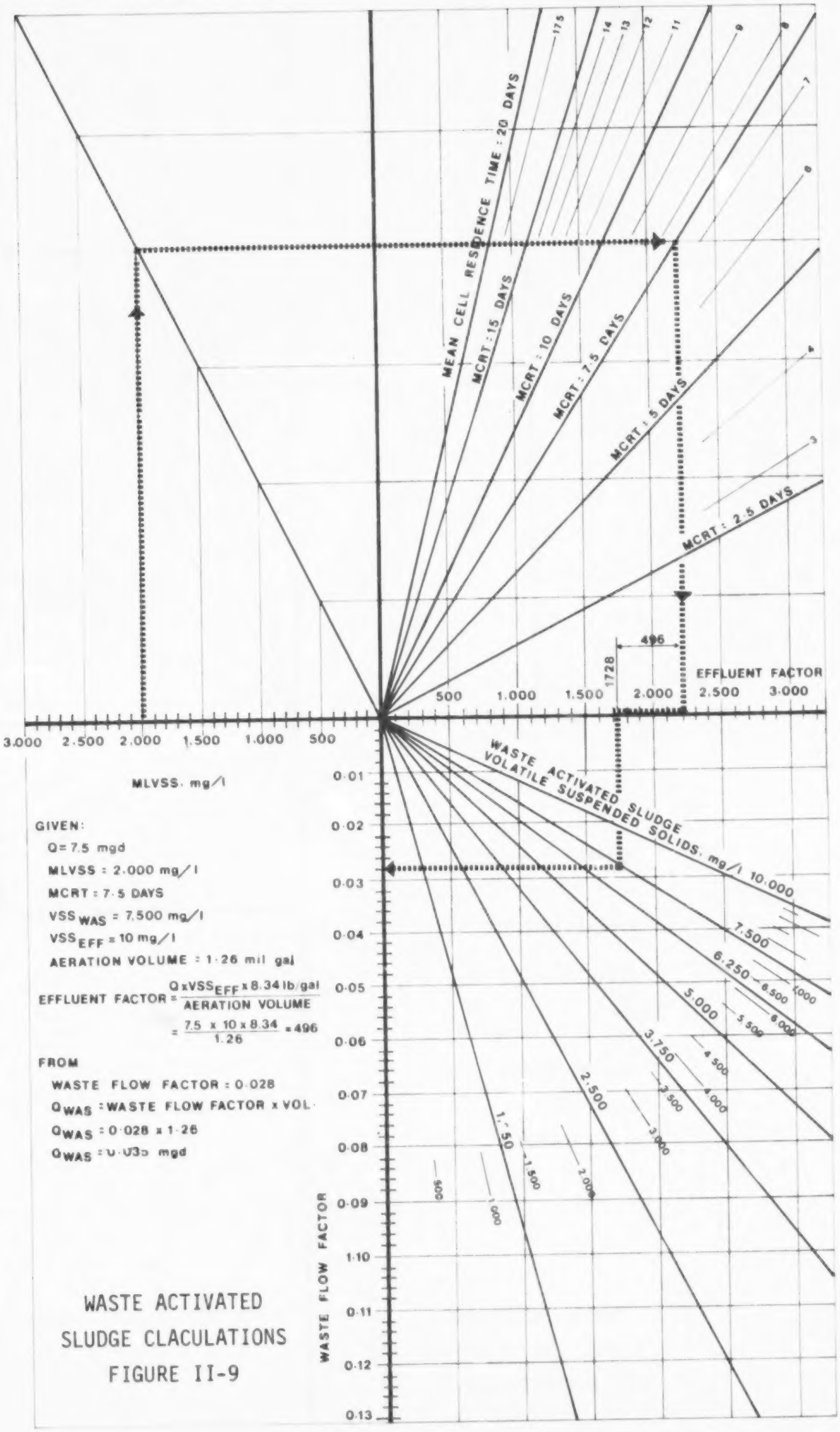
FROM
WASTE FLOW FACTOR = 0.035

Q_{WAS} = WASTE FLOW FACTOR x VOL.

Q_{WAS} = 0.035 x 1.26

Q_{WAS} = 0.044 mgd

WASTE ACTIVATED
SLUDGE CALCULATIONS
FIGURE II-8



GIVEN:

- $Q = 7.5$ mgd
- MLVSS : 2.000 mg/l
- MCRT : 7·5 DAYS
- VSS_{WAS} = 7.500 mg/l
- VSS_{EFF} = 10 mg/l
- AERATION VOLUME : 1·26 mil gal

$$\text{EFFLUENT FACTOR} = \frac{Q \times VSS_{EFF} \times 8.34 \text{ lb/gal}}{\text{AERATION VOLUME}}$$

$$= \frac{7.5 \times 10 \times 8.34}{1.26} = 496$$

FROM

- WASTE FLOW FACTOR : 0·028
- Q_{WAS} : WASTE FLOW FACTOR x VOL·
- Q_{WAS} : 0·028 x 1·26
- Q_{WAS} : 0·035 mgd

WASTE ACTIVATED SLUDGE CLACULATIONS
FIGURE II-9

What does all these calculations mean?

This means that for the next 8 days approximately 45,000 gallons per day should be wasted from the RAS system. However, the WAS flow rate should be determined and adjusted daily to maintain the desired MCRT.

Graphical solution for WAS calculations.

Figures II-8 and II-9 present a graphical technique for making WAS flow rate calculations for maintaining a constant MCRT. These figures are identical except the Figure II-8 excludes the volatile suspended matter contained in the effluent. This is done because some operators feel a very low amount of soilds in the effluent does not significantly effect the MCRT while others do. Figure II-9 includes the correction for effluent solids.

The following illustration will show how to determine the WAS flow rate with these figures.

Step-by-Step.

1. Refer to Figure II-8.
    - Locate the MLVSS concentration for your plant in the MLVSS axis. 2000 mg/l
    - Draw a line that is parallel to the bold vertical axis. Stop at the sloping bold line.
    - Proceed parallel to the MLVSS axis to the MCRT being used for operation. 7.5 days
    - Note that the MCRT values range from 2.5 to 20 days, in 1 day increments up to 15 days and 2.5 day increments up to 20 days.
    - Draw a line parallel to the bold vertical axis and intersect the VSS_{WAS} for your plant. Note that the concentrations are shown in increments of 500 mg/l with a range of 500 to 10,000 mg/l. Thus these figures can be used for calculations involving wasting from the RAS or the mixed liquor. In Figure II-9 when you get to the effluent factor axis, deduct the lbs/day solids in the effluent then proceed to the VSS_{WAS} for your plant. 7500 mg/l
    - At the intersection with the VSS_{WAS} line, draw a line parallel to the MLVSS axis. Read the value indicated on the axis labeled waste flow factor = 0.035
    - Now multiply the factor by the aeration tank volume of your plant to determine the WAS flow rate 0.044 mgd

This value of Q_{WAS} is very close to the value calculated in the example problem. The use of these figures is a convenient and accurate method for calculating the WAS flow rate.

Sludge Quality Control

The sludge quality control method for process control may be used independently or in conjunction with other control methods presented in this section of the manual.

The control program includes the following laboratory tests and observations:

- 30-minute sludge settleability test
- Measurement of sludge blanket depth
- MLSS concentration by centrifuge test
- RAS concentration by centrifuge test
- Secondary effluent turbidity
- D.O.
- Microscopic examination of MLSS
- Aeration tank observations
- Secondary clarifier observations

The data obtained from the control and monitoring tests are plotted on graphs against time. These data trend plots are based on 5-day moving averages and are utilized for making control adjustments to optimize process performance. The overall objective of this control method is based on maintaining an activated sludge quality which produces the best effluent.

The control tests (depth of blanket, settleometer and centrifuge, etc.), nomenclature and many process relationship calculations are those proposed by E.B. Mallory in the 1940's. The following procedures to determine the required interrelated process control adjustments were evolved by West:

> West claims that best process performance depends upon satisfying all interrelated process requirements simultaneously; not by exclusive dependence upon any single or preconceived factor.

A series of EPA pamphlets, entitled "Operational Control Procedures for the Activated Sludge Process," describing these procedures have been developed by the Operational Technology Branch (formerly NFIC-C) of the Municipal Operations and Training Division, Cincinnati, Ohio. Simplification of these procedures were prepared by Owen K. Boe of the EPA Region VIII Office, Denver, Colorado, in a paper entitled "Activated Sludge Control with a Settlometer and Centrifuge." The following procedures are derived from the above publications.

Mass Balance by Centrifuge

The centrifuge test is used to measure sludge concentration because it saves time over the regular suspended solids test. When sludge separates in the centrifuge, the amount is measured as a percent of the total volume. The centrifuge tube is calibrated from 0 to 100 percent.

A sludge unit system has been developed to express the results of the centrifuge test in a simple and meaningful manner. In order to know how this system works, we need to know how many microorganisms are in the aeration tank. A representative sample is taken from the tank and placed into the centrifuge. A 15 minute spin reveals that the level of separated sludge is 1.0 percent of the volume in the centrifuge tube. However, before the microorganisms measured can be compared to the microorganisms in the aeration tank, we must have a system to calculate this quantity. Looking at our aeration tank system we see that the centrifuge reads 1.0 percent and the tank volume is 1.0 MG (million gallons). Therefore, this quantity of microorganisms is defined as 1.0 sludge unit, or as shown in the formula:

$$1.0\% \times 1.0\text{ MG} = 1.0\text{ Sludge Unit}$$

NOTE: It should be noted by the reader that the centrifuge results are recorded in percent; however, the decimal percent expression is disregarded in order to simplify the calculations.

To understand how this system works, let's look at a couple more examples:

1. Suppose the same aeration tank had twice as many microorganisms present. Now, when we run the sample on the centrifuge we find that the separated sludge reads 2.0%. Now, the sludge units are calculated to be:

   $$2.0\% \times 1\text{ MG} = 2\text{ Sludge Units}$$

   which shows twice as many microorganisms as before.
2. Let's also consider what would happen if we had two aeration tanks instead of one. If both aeration tanks had a reading of 1 percent sludge, then the sludge units would calculate to:

   1st tank - 1% × 1 MG = 1.0 Sludge Unit
   2nd tank - 1% × 1 MG = 1.0 Sludge Unit
   Total Sludge Units = 2.0

We now have a system which can be used to measure the quantity of microorganisms in the plant which only involves two numbers. The first number is the percent reading taken from the centrifuge and the second number is the volume of the aeration tank (in million gallons). Since the volume of the tank usually stays the same, all that is needed to determine the quantity of microorganisms is a reading from the centrifuge, and this reading only takes a few minutes to determine.

If we wanted to, we could convert the sludge units to pounds of sludge. All that is needed for this is to run a suspended solids (SS) test and a spin test on the same sample. For the previous example, which had a spin of 1%, the SS were found to be 1000 mg/l. This gives a spin ratio of 1000 mg/l/1%. To calculate pounds, use the following formula:

$$\text{lbs} = \%\text{ spin} \times \text{spin ratio} \times 8.34 \times \text{Vol (million gallons)}$$

So, as in the previous example where the tank volume was 1 MG and the spin ratio was 1000 mg/l/1%, we have:

$$\text{lbs} = \frac{(1\%)(1000\text{ mg/l})}{1\%} \times \frac{(8.34\text{ lbs})}{\text{gal}} \quad (1\text{ mg})$$

Therefore:

$$\text{lbs} = 8340\text{ lbs}$$

The sludge unit system may sound a little different at first and may sound like more work, but it actually provides the plant operator with a tool that can be used over and over and in many different ways with relatively little time involved. Also, as will be shown later, the use of these units and data obtained from the settleometer provides the operator with very useful data for controlling return sludge rates.

Some good examples of how the centrifuge and the sludge unit system may be used for process control and evaluation are described below.

1. Aeration Sludge Units — ASU

This is a measurement of the amount of sludge found in the aeration tanks. ASU's are calculated by multiplying the aeration tank volume in millions of gallons (AVG) by the daily average aeration tank concentration (ATC). The Aeration Sludge Units are determined as follows:

Example Calculation

A. Data Required
   1. AVG = Aeration volume, million gallons = 1.0
   2. ATC = Aeration tank Conc., % = 3.0

B. Now determine the Aeration sludge Units.

$$\begin{aligned} \text{ASU} &= (\text{AVG})(\text{ATC}) \\ &= (1.0)(3.0) \\ &= 3 \text{ units} \end{aligned}$$

2. Clarifier Sludge Units - CSU

This is a measurement of the amount of sludge found in the clarifier. CSU's are calculated by multiplying the volume of sludge in the clarifier in millions of gallons (CVG) by the average concentration of the sludge in the clarifier. The volume of sludge in the clarifier is found by finding the fraction of the total clarifier volume that is filled with sludge.

The volume of sludge is determined by the following formula and defining CVG as volume of clarifier and DOB as the measured distance from the water surface to the top of the sludge blanket. Therefore:

$$\text{Sludge Volume} = \left[\frac{\text{Average depth of Clarifier - DOB}}{\text{Average depth of Clarifier}}\right]$$

The average sludge blanket concentration is found by assuming the concentration at the top of the blanket is equal to the aeration tank concentration (ATC) and the concentration at the bottom of the blanket is equal to the return sludge concentration (RSC). These assumptions are made since we know the sludge is compacting at the bottom of the clarifier, but we can't really measure the average concentration. The average concentration is then assumed to be:

$$\text{Average Sludge Concentration} = \frac{\text{ATC} + \text{RSC}}{2}$$

Now in order to find the total clarifier sludge units, multiply the percent sludge by the average sludge concentration. Clarifier sludge units are then determined as follows:

Example Calculation

A. Data Required
  1.* CVG = Clarifier volume, million gallons = 0.70
  2. ATC = Aeration tank concentration, % = 3
  3. RSC = Return sludge concentration, % = 12
  4. DOB = Depth of sludge blanket, ft. = 8
  5. ACD = Average clarifier depth, ft. = 10

B. Determine the volume of sludge in the clarifier.

$$\text{Sludge Volume} = \frac{(\text{ACD} - \text{DOB})\ {}^{*}\text{CVG}}{\text{ACD}}$$

$$= \frac{(10 - 8)\,0.70}{10}$$

$$= (0.2)\,(0.70)$$

$$= 0.14$$

C. Determine the average sludge blanket concentration.

$$\text{Average Sludge Concentration} = \frac{\text{ATC} + \text{RSC}}{2}$$

$$= \frac{3 + 12}{2}$$

$$= 7.5$$

D. Now determine the Clarifier Sludge Units.

$$\text{CSU} = (\text{Sludge Volume})\,(\text{Average Sludge Conc.})$$

$$= (0.14)\,(7.5)$$

$$= 1.05 \text{ units}$$

*Perform the calculations within parenthesis first.

3. Total Sludge Units - TSU

This is the measurement of the total amount of activated sludge in the system. The varying amounts of sludge in the clarifier are included in this measurement.

Total sludge units are determined as follows:

Example Calculation

A. Data Required
   1. ASU = Aeration sludge unit = 3.0
   2. CSU = Clarifier sludge unit = 1.05

B. Now determine the total sludge units.

$$\begin{aligned} TSU &= ASU + CSU \\ &= 3.0 + 1.05 \\ &= 4.05 \text{ units} \end{aligned}$$

4. Return Sludge Units — RSU

This is the measurement of the daily average of sludge units returned from the clarifier to the aeration tank.

The return sludge units are determined as follows:

Example Calculation

A. Data Required
   1. RSC = Average return sludge concentration, % = 12
   2. RSF = Average return sludge flow, mgd = 2

B. Now determine the return sludge units.

$$\begin{aligned} RSU &= (RSC)(RSF) \\ &= (12)(2) \\ &= 24 \text{ units/day} \end{aligned}$$

5. Clarifier Sludge Flow Demand —CSFD

Assuming that the sludge settling concentrations* (SSC_t) determined in the settleometer test relate to the return sludge concentration (if the sludge had stayed in the clarifier for the same length of time), the required return sludge flow rate can be determined as follows:

Example Calculation

A. Date Required

1. Q = Plant flow rate, mgd = 4
2. RSF = Return sludge flow, mgd = 2
3. RSC = Return sludge concentration, % = 12
4. ATC = Aeration tank concentration, % = 3.0
5. SSC_{60} = 60 minute sludge settling concentration, % = 10

$$^{*}SSC_t = \frac{(\text{Aeration tank conc., \%})(1000\ \text{ml/l})}{\text{Sludge settling volume}_t,\ \text{ml/l}}$$

t = time

B. Now determine the clarifier sludge flow demand.

$$CSFD = \frac{(RSF)(RSC - ATC)}{SSC_t - ATC}$$

$$= \frac{(2)(12 - 3)}{10 - 3}$$

$$= \frac{(2)(9)}{7}$$

$$= 2.6\ \text{mgd}$$

Therefore, the return sludge flow rate should be increased from 2 to about 2.6 mgd. The sludge blanket depth measurement in the final clarifier should be taken into consideration before making any changes in the return sludge flow rate.

Some trial and error adjustments may be required using the sludge blanket depth measurement as the final guide.

In general, the following rules of thumb can be applied when comparing the return sludge concentration (RSC) to the 60 minute and 30 minute sludge settling concentration (SSC):

- If the RSC is greater than the SSC_{60}, increase the return sludge rates.
- If the RSC is less than the SSC_{30}, decrease the return sludge rates.

Like all rules of thumb, other plant conditions have to be considered, such as flexibility in the return sludge system, clarifier sludge blanket depth measurements, aeration detention times, etc.

6. Waste Sludge Units - WSU

This is the measurement of the total quantity of sludge wasted from the system each day. Sludge wasting can occur intentionally by pumping sludge to a digester or it can occur unintentionally by being carried over the clarifier weirs. Usually the amount of sludge lost over the clarifier weirs is small in comparison to that which is intentionally wasted. However, to check this out or to measure the quantity of the sludge unit system, we can make use of the spin ratio.

Effluent sludge units (ESU) are calculated by measuring the total suspended solids in the effluent, dividing by the spin ratio, and multiplying by the plant daily average flow. Therefore:

$$\text{ESU} = \frac{(\text{TSS})(\text{Flow})}{\text{Spin Ratio}}$$

Intentional sludge wasting (XSU) is calculated by taking the daily average concentration of sludge wasted (WSC) and multiplying the volume (in million gallons) of sludge wasted (WSF). Therefore:

$$\text{XSU} = \text{WSC} \times \text{WSF}$$

The total sludge wasted (WSU) is then determined by adding the effluent sludge units to the intentional sludge units. The total sludge wasted units are determined as follows:

Example Calculation

A. Data Required
   1. TSS = Total suspended solids in clarifier effluent, mg/l = 30
   2. Flow = Plant daily average flow, mgd = 4
   3. Spin Ratio = Suspended solids conc., mg/l/centrifuge sludge conc., % = 1000/l
   4. WSC = Average waste sludge concentration, % = 15
   5. WSF = Average waste sludge flow, mgd = 0.05

B. Determine the effluent sludge units.

$$\text{ESU} = \frac{(\text{TSS})(\text{Flow})}{\text{Spin Ratio}}$$

$$= \frac{(30)(4)}{1000/1} = (30)(4)\frac{1}{1000}$$

$$= 0.120 \text{ units/day}$$

C. Determine the units of sludge intentionally wasted.

$$\text{XSU} = (\text{WSC})(\text{WSF})$$

$$= (15)(0.05)$$

$$= 0.75 \text{ units/day}$$

D. Now determine the total sludge wasted.

$$\begin{aligned} WSU &= ESU + XSU \\ &= 0.12 + 0.75 \\ &= 0.87 \text{ units/day} \end{aligned}$$

Sludge wasting is regulated on the basis of maintaining a "normal settling", good quality sludge as measured by the settleometer and on the basis of visual observations of the aeration tank and clarifier surfaces. The following is a summary of Sludge Waste Control.

Sludge wasting should normally be started, or increased, if and when:

a. Mixed liquor settles too rapidly in the settleometer and SSC_{60}* rises significantly above 20
b. "Ash" or "clumps" start rising to the final clarifier surface.
c. A dark-brown, scummy foam appears on the aeration tank surface.
d. A sludge blanket, composed of good quality normally settling sludge, rises too close to the clarifier water surface.

Sludge wasting should be reduced, if and when:

a. Mixed liquor settles too slowly in the settleometer and SSC_{60} values fall to 10 or less. (This will normally be accompanied by a rising clarifier sludge blanket.)
b. Large billows of white foam start forming on the aeration tank surface.

$$^{*}SSC_{60} = \frac{(\text{Aeration tank conc., \%})(1000\ \text{ml/l})}{\text{Sludge settling volume}_{60}\text{, ml/l}}$$

Changes in the wasting rate should be made a little each day (10 to 15 percent per day). Since sludge quality responds slowly to process control changes (usually about three days after the adjustments are made), process control changes should not be made rapidly or irregularly.

About a week is usually required following the control adjustments before the trend in the process response can be positively confirmed. And finally, two to four weeks before the biological process stabilizes.

7. Sludge Age - Age

Sludge Age or mean cell residence time (MCRT) has been used by many authors as an operational tool. The purpose is to define an average time that activated sludge stays in the plant. To find sludge age we need only to divide the total sludge units by the total sludge wasted per day.

This may be calculated as follows:

Example Calculation

A. Data Required
   1. TSU = Total sludge units in system = 4.05
   2. WSU = Total sludge wasted, units/day = 0.87

B. Now determine the sludge age.

$$\text{Age} = \frac{\text{TSU}}{\text{WSU}}$$

$$= \frac{4.05}{0.87}$$

$$= 4.7 \text{ days}$$

In the Sludge Quality method of process control, conventional parameters such as F/M and MCRT are calculated for monitoring and comparative purposes; but are not used as control parameters.

8. Sludge Detention Time in the Clarifier - SDTc

This is a measurement of the average time that the activated sludge actually spends in the clarifier at any given time. SDTc is found by dividing the clarifier sludge units by the average daily return sludge units and multiplying by 24 hrs/day to obtain the time in hours.

Example Calculation

A. Data Required
   1. CSU = Clarifier sludge units/day = 1.05
   2. RSU = Return sludge units/day = 24

B. Now determine the sludge detention time in the clarifier.

$$\text{SDTc} = \frac{(\text{CSU})(24 \text{ hrs/day})}{\text{RSU}}$$

$$= \frac{(1.05)(24)}{24}$$

$$= 1.05 \text{ hours}$$

Sludge detention time in the clarifier should be greater than 30 minutes to provide time for compaction. Any time less than 30 minutes will usually require a high return rate which will reduce the sludge detention time in the aerators. (See discussion of SDTa, No. 9 below.) The sludge detention time in the clarifier should be less than 60 minutes to preserve an "active biomass".

9. Sludge Detention Time in the Aerator - SDTa

This is the measurement of the average time that the activated sludge actually spends in the aerator mixing with wastewater. The sludge detention time affects the efficiency of the organisms to absorb and make use of the BOD by changing the contact time with the BOD. A comparison of sludge detention times in the aeration tank to the clarifier also provides important information for controlling sludge quality. The operator can control or change his sludge detention times by changing return rates.

A rule of thumb has been developed which relates the sludge detention time in the aeration tank to the detention time in the final clarifier:

$$\frac{\text{SDTa}}{\text{SDTc}} = \text{value must be greater than 1}$$

This rule of thumb is based on observations of sludge quality in various plants where it has been noticed that as SDTa becomes closer to SDTc, that sludge quality is much more difficult to control.

Tank design, especially in some complete mix plants, may limit the ability of the operator to control this ratio above one, but this still should be a goal of plant operations.

SDTa is found by dividing the aeration sludge units by the sludge units being sent to the clarifier per day, and multiplying by 24 hrs/day. The sludge flow to the clarifier is found by adding the plant flow (Q) to the return flow (RSF) and multiplying by the aeration tank concentration (ATC).

The sludge detention time in the aeration tank is determined as follows:

Example Calculation

A. Data Required
   1. ASU = Aeration Sludge Units = 3.0
   2. Q = Plant flow rate, mgd = 4
   3. RSF = Return sludge flow, mgd = 2
   4. ATC = Aeration tank concentration, % = 3.0

B. Now determine the sludge detention time in the aeration tank.

$$\text{SDTa} = \frac{(\text{ASU})(24 \text{ hrs/day})}{(\text{Q} + \text{RSF})(\text{ATC})}$$

$$= \frac{(3.0)(24)}{(4 + 2)(3.0)}$$

$$= 4 \text{ hours}$$

Settleometer

The settleometer (also called the sludge settleability test) is the key indicator for observing sludge quality. Diligent use of the settleometer can provide an experienced operator with days advance warning of an impending disruption or change in process control. This advance warning provides the operator with valuable time to make appropriate process changes. The settleometer information can also be instrumental when recovering from an unavoidable operational upset.

In this case the advanced indicators can guide the operator through a series of process adjustments without wasting excess time waiting for results from process changes or without trying to make a major adjustment in too short a time.

The two things an operator should look at when running the settleometer test are the floc formation and the blanket formation. Through experience, an operator will soon learn that within a few minutes he can detect certain characteristics which will describe the sludge quality. Is the floc granular, compact, fluffy or feathery? Does the floc settle individually or does it first form a blanket? Is the blanket ragged and lumpy, or uniform on the surface?

After the operator has looked at these characteristics he then should observe settling rates and compaction characteristics. Is the blanket settling uniformly, or are segments settling faster than others? Is the blanket entrapping the majority of the material or are straggler floc escaping? Is the sludge compacting and squeezing out water, or is it maintaining a constant density throughout?

Observations such as these are important to the operator. They are not easily translated to numbers, so he should make appropriate notes on his data sheet for future reference. There are, however, numerical observations which can be made. Figure II-10 presents a typical data sheet which can be used to record appropriate sludge settling parameters. Observations and recordings are made every 5 minutes for the first half hour, and then every 10 minutes for the second half hour. More observations are made in the first half hour to ensure that the operator is taking the time to observe the floc formation and blanket characteristics.

If the operator also measures the concentration from the original aeration tank sample with the centrifuge (ATC) he can make some informative calculations from the data.

The calculation of interest is the conversion of the sludge settling volume (SSV) to sludge settling concentrations (SSC) which is determined for any given time (t) of settling as follows:

Facility Clear Creek

Date 6/12/73

Day Saturday

SETTLEOMETER TEST INFORMATION								
Time of test								
Time	SSV cc/l	SSC* %	Time	SSV cc/l	SSC* %	Time	SSV cc/l	SSC* %
0	1000	3.4	0	1000	2.8	0	1000	
5	950	3.58	5	910	3.08	5		
10	890	3.82	10	820	3.42	10		
15	830	4.10	15	740	3.79	15		
20	770	4.42	20	670	4.18	20		
25	720	4.73	25	620	4.52	25		
30	680	5.00	30	570	4.92	30		
40	620	5.48	40	490	5.72	40		
50	570	5.97	50	430	6.52	50		
60	520	6.54	60	380	7.38	60		

ATC RSC DOB TURB & FLO INFORMATION					
TIME	ATC—%	RSC—%	DOB—Ft	Turb—JTU	INF FLO
900a	3.4	8.6	6.0	3.2	1.5
100p	2.8	9.0	3.0	3.7	
500p	3.0	9.1	3.5	3.5	
1000p	3.1	9.0	4.5	3.0	
Sub-Tot					
Total					
Aver	3.1	8.9	4.2	3.3	1.5

WASTING INFORMATION								
Time Wasting Began	Time Wasting Ended	Total Time Wasted (min)	Flow Rate (GPM)	Gallons Wasted (GAL)	WSC Began (%)	WSC Ended (%)	Average WSC (%)	Sludge Units Wasted (GAL X %)
700a	200p	300	90	27,000	9.2	10.0	9.6	.26
							Total	

RSF INFORMATION				
Time Began	Time Ended	Total Time (min)	RSF (GAL min)	Total (GAL)
800a	800a	1440	1000	1.4
			Total	1.4MG

BOD5 TEST INFORMATION							
Parameter							BLK
Bottle #							
% Dilution							
Initial D.O.							
Final D.O.							
D.O. Deplet.							
Factor							
mg/l BOD_5							

MISC. INFORMATION

TSS & VSS TEST INFORMATION					
Parameter					
Time					
Tare #					
Tare & Solids WT.					
Tare WT.					
Dry Solids WT					
Ash WT.					
Volatile WT.					
Vol. of Sample					
TSS mg/l					
VSS mg/l					
% VSS					

$*SSC = \frac{ATC \times 1000}{SSV}$

NOTE: Normal Data period is from 0800 on the date shown and continues for 24 hrs.

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ACTIVATED SLUDGE PLANT
DAILY DATA SHEET
FIGURE II-10

Example Calculation

A. Data Required

1. ATC = Aeration tank concentration, % = 3.4
2. $SSV_{(t)}$ = Sludge settling volume at any time, ml/l = 680 (at 30 min.)
3. (t) = Length of time of settling, minutes = 30

B. Now determine the sludge settling concentration.

$$SSC_{(t)} = \frac{(ATC)(1000\ ml/l)}{SSV_{(t)}}$$

$$SSC_{30} = \frac{(ATC)(1000\ ml/l)}{SSV_{30}}$$

$$= \frac{(3.4)(1000)}{680}$$

$$= 5\%$$

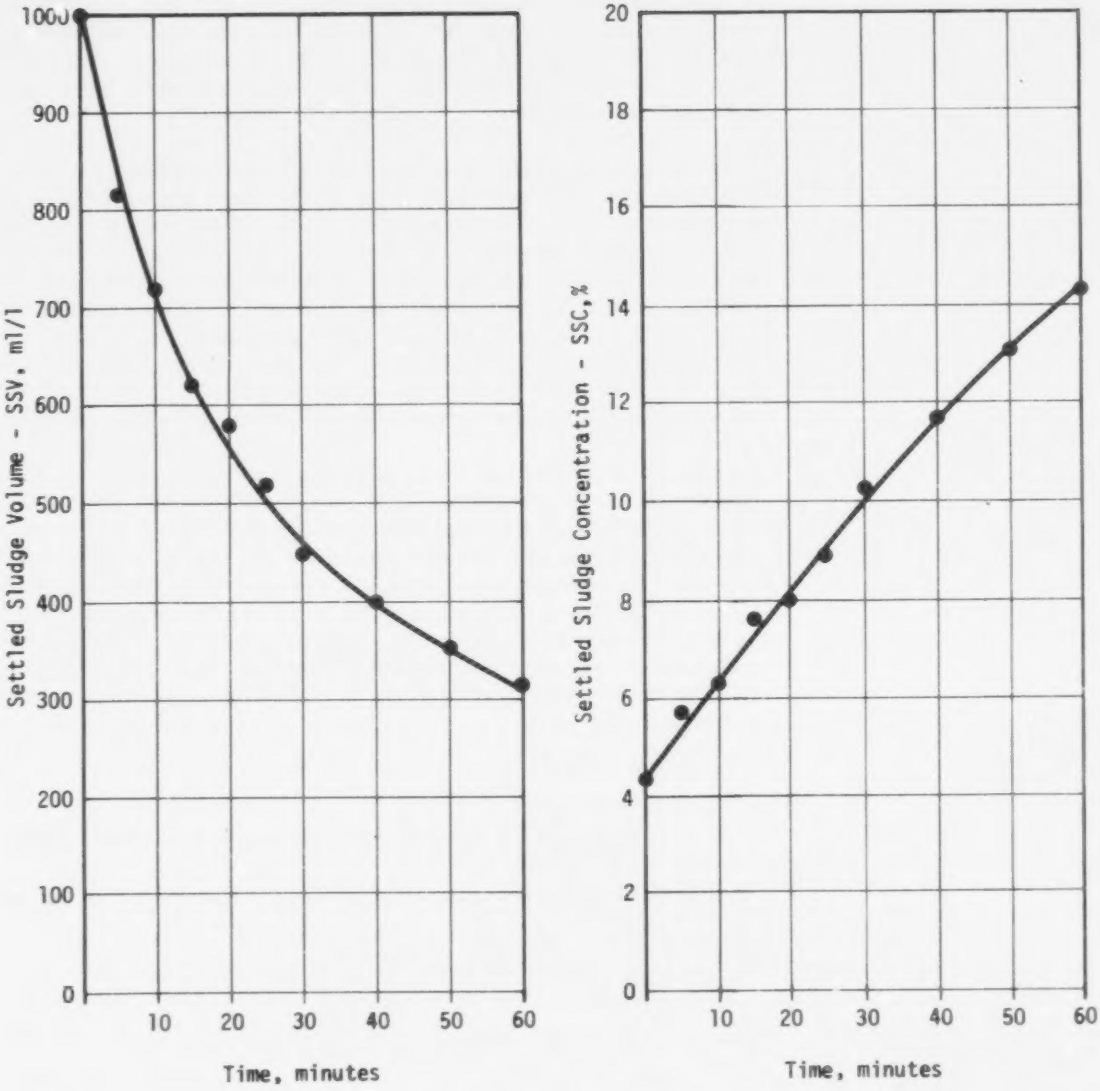
This means that after 30 minutes the sludge has settled to a concentration of only 5%.

The sludge settling concentrations can be calculated for various times and plotted (as shown in Figure II-11) corresponding to the time and day they were observed. When several days of data have been plotted, a trend will have been developed which graphically relates to the settling characteristics observed in the settleometer. Often, it is found that the 5 minute, 30 minute, and 60 minute SSC's adequately represent the settling characteristics.

The 5 minute sludge settling concentration is an indicator of the critical floc and blanket formation stage. Here the operator's observations and notes are very important for future reference.

The majority of the settling occurs before the 30 minute reading, therefore the distance settled reflects the settling rate of the sludge. For example, a 30 minute sludge settling volume of 200 would indicate a fast settling sludge, while a settling volume of 600 would represent a very slow settling sludge.

The 60 minute sludge settling concentration is indicative of the level of compaction that can be expected from the sludge. Therefore, there is a relationship between this concentration and the concentration of the return sludge that is actually observed in the plant. These numbers will seldom be the same due to flow characteristics and other physical differences found in the clarifiers. The important criteria, however, is that the settleometer characteristics are reproducible for similar sludge quality characteristics. This then enables the operator to make some decisions on return sludge flows form settleometer data.



PLOTTING SLUDGE SETTLING CHARACTERISTICS

FIGURE II-11

A "normal settling" good quality sludge will concentrate to a SSC_{60} range of about 12 to 18 in one hour and won't settle any more after two hours.

A "rapidly settling" sludge is an overoxidized sludge that will concentrate to a SSC_{60} range greater than 20 in one hour and won't settle any more after an hour. Rapidly settling sludge is often accopanied by such clarifier problems as ashing or clumping. The corrective actions for these problems are described in Section I, "TROUBLESHOOTING".

A "slow settling" sludge that only concentrates to a SSC_{60} of 10 or less and takes 3 or 4 hours to reach final settling and compaction is usually a young sludge. A very young sludge may not settle at all during the first 5 to 10 minutes, and may only concentrate to between 700 and 900 ml/l during the first hour. Young sludge is often accompanied by a high sludge blanket in the final clarifier with an imminent danger of sludge bulking and/or solids washout. The sludge wasting should be reduced to increase the sludge settleability towards the "normal" range. The return sludge flow rate may need increasing to lower the blanket level. Corrective measures for this problem are presented in Section I, "TROUBLESHOOTING".

Sludge settling rates can be used by the operator to numerically relate one set of sludge characteristics to another. These settling rates can be used by the operator to describe a rate of settling for which the plant provides a good quality effluent. Generally this rate will fall between 400 and 1200. This corresponds to a 30 minute reading on the settleometer of 400 to 800 milliliters. As mentioned before, this information should always be accompanied by notes which relate to the more important, but not quantitative, data of floc and blanket formation. The sludge settling rate (SSR) is the increase in sludge concentration per hour and is determined as follows:

Example Calculation

A. Data Required
   1. SSV_{30} = 30 minute sludge settling volume, ml/l = 680

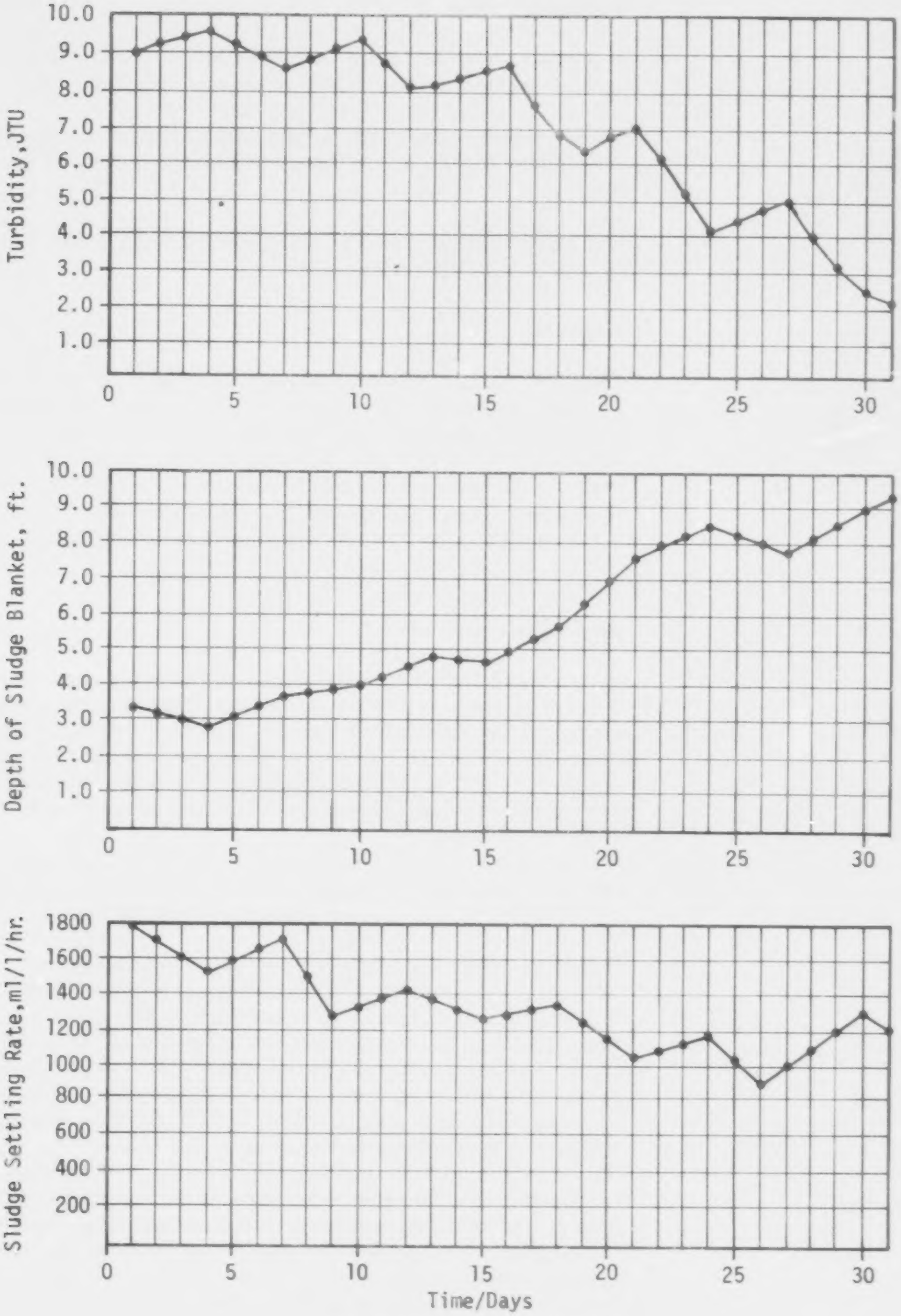
B. Perform the following calculation to determine the sludge settling rate.

$$SSR = \frac{(1000 - SSV_{30})}{0.5\text{ hr.}}$$

$$= \frac{(1000 - 680)}{0.5}$$

$$= 640\text{ ml/l/hr.}$$

The turbidity of the clarifier effluent, the depth of the sludge blanket, sludge settling rates, and sludge characterisitcs (floc and blanket formation) should be plotted on trend charts as shown on Figure II-12 to help the operator in maintaining control of his facility.



PROCESS VARIABLE TRENDS
FIGURE II-12

Visual Observations

A modest accumulation of light colored, crisp-appearing foam on the aeration tanks is usually indicative of good operation.

During good operation the final clarifier effluent will be relatively clear with the sludge blanket in the lower half of the clarifier (generally 1 to 3 feet).

For those observations that are indicative of operational problems, see Section I, "TROUBLESHOOTING".

Turbidity

Turbidity is a quick and convenient indication of the activated sludge process performance. A well performing activated sludge plant should be producing an effluent with a settled turbidity of less than 3 JTU's and sometimes down to 1 JTU. Turbidity measurements can also be used to measure the degree of severity of pin floc or other solids. Short term variations due to these type problems may be attributable to hydraulic problems in the clarifier rather than deterioration of the sludge quality.

Depth of Blanket

Within the final clarifier, a separation of the liquid and solids takes place. The solids settle to the bottom of the clarifier while the clear liquid is displaced over the clarifier effluent weirs. If the settled solids are not removed from the tank at a rate equal to or greater than solids input by the aeration effluent flow, a blanket of sludge will accumulate until eventually the solids are washed out in the clarifier effluent flow.

The location of the sludge blanket in relation to the clarifier depth may be determined by various types of devices—some are commercially available, while others must be improvished by the operator.

Determining the sludge blanket depth in the final clarifier in conjunction with other measurements, such as the plant flow, aeration tank concentration (ATC), sludge settling concentration (SSC), and the return sludge flow (RSF) and concentration (RSC) provides valuable information that can be used to control the return sludge flow rates. Additionally, these measurements can be used to evaluate the operation of multiple units, for instance the sludge blanket depth in two clarifiers operating in parallel (both receiving flow from same aeration basin) having equal return sludge flow rates should be comparable. If the sludge blanket in one clarifier was rising while the blanket in the other clarifier was falling, it could be concluded that the aeration tank effluent flow was being unevenly distributed to the clarifiers. Depth of blanket measurements are important for an operator so he can have early warning to clarifier malfunctions and to problems associated with long storage times in the clarifier. An average value for each clarifier is usually sufficient for process control, but measurements should be periodically made at various locations in the clarifier to detect any localized problems. Coning or plugging of suction ports can lead to areas in the clarifier where the sludge blanket will build. A rising blanket may indicate an inadequate sludge return rate, unbalanced distribution of aeration tank effluent flow, inadequate sludge wasting rates, or a poorly settling sludge.

The presence of a poorly settling sludge could be verified with the SSC value. To correct a rising blanket, the operator first determines the reasons by a review of the lab test results, operational logs, and process control parameters. After determining the possible reason for the increased blanket depth, the operator should then take the appropriate corrective measures.

The procedures for making the sludge blanket measurement are given in Section IV, "LABORATORY CONTROL".

Microscopic Examination

Microscopic examination of the MLSS can be a significant aid in the evaluation of the activated sludge process. The presence of various microorganisms within the sludge floc can rapidly indicate good or poor treatment. The most important of these microorganisms are the heterotropic and autotrophic bacteria which are responsible for purifying the wastewater.

In addition, protozoa play an important role in clarifying the wastewater and act as indicators of the degree of treatment. The presence of rotifers is also an indicator of effluent stability. A predominance of protozoa (ciliates) and rotifers in the MLSS is a sign of good sludge quality.

Inversely, a predominance of filamentous organisms and a limited number of ciliates is characteristic of a poor quality activated sludge. This condition is commonly associated with a sludge that settles poorly.

There are many other organisms such as nematodes (worms) and waterborne insect larvae which may be found; however, these do not significantly affect the quality of treatment.

The microorganisms which are important to the operator are the protozoa and rotifers. The protozoa eat the bacteria and help to provide a clear effluent. Basically, the operator should be concerned with three groups of protozoa, each of which have significance in the treatment of wastewater. A discussion of these groups and the procedures for performing a microscopic examination are presented in Section IV, "LABORATORY CONTROL".

2.05 OPERATIONAL PROBLEMS

Common operational problems.

This section of the manual discusses operational problems commonly experienced in the activated sludge process. In general, these problems can be classified by conditions which the operator can see in the aeration tank and secondary clarifier.

- *Aeration Tank:*
  1) Aeration Tank:
  2) Foaming Problems
- *Secondary Clarifier*
  3) Solids Washout
  4) Bulking Sludge
  5) Clumping/Rising Sludge
  6) Clouding Secondary Effluent
  7) Ashing
  8) Pinpoint Floc
  9) Stragglers/Billowing Solids

Corrections can be made by a logical approach.

Correction of these problems can be approached in a logical manner, by using sound operational control practices and by maintaining proper equipment operation. Troubleshooting procedures covering these problems are provided in an easy-top-follow format in Section I, "TROUBLESHOOTING."

The 30-minute settling test provides data for problem solving.

The problems occurring in the clarifier can often be associated with observations made during the 30-minute settleability test. This test is used to indicate the settling characteristics of the mixed liquor under controlled conditions. Figures II-16 , II-20, and II-22 present pictorial guides for interpretation and application of the various settling test observations. The procedures for performing the settleability test can be found in Section IV, "LABORATORY CONTROL."

Aeration System Problems (Refer to Figure II-13)

Why is aeration important?

Aeration and mixing of the MLSS is essential to maintain the environment for the microorganisms to remain active and healthy. In addition, mixing of the aeration tank contents is necessary in order to bring these microorganisms in contact with all the organic matter in the wastewater being treated.

Uniform aeration & mixing is essential.

Mixing in the aeration tank can generally be checked by observing the turbulence on the aeration tank surface. The surface turbulence should be reasonably uniform throughout the tank. Dead spots and nonuniform mixing patterns will generally indicate a clogged diffuser or that the diffuser header valves need adjustment to balance the air distribution in the tank. An illustration of violent turbulence in an aeration tank is shown in Figure II-13.

Perform D.O. profile.

Periodically, (generally monthly to every 6 months) a D.O. profile should be performed in aeration tanks which are equipped with the diffused-type of aeration system. The air distribution should be adjusted to maintain a D.O. of no less than 0.5 mg/l, preferably 1 to 3 mg/l, throughout the aeration tank.

Some causes for aeration problems.

Some probable causes of nonuniform aeration include the following:

1. Air rates too high or low for proper operation of the diffuser.
2. Valves need adjustment to balance the air distribution.
3. Diffusers (or mechanical aerators) need repair and/or cleaning. Masses of air rising over the location of the diffuser blowoff legs (if so equipped) generally indicates that the diffusers need cleaning. Figure II-13 is an indication of this problem.
4. Mechanical equipment limitations.

Corrective action for aeration problems.

The following applicable measures should be implemented to correct aeration problems:

- Adjust air SCFM rate to maintain the D.O. in the proper range (1 to 3 mg/l). The SCFM of air per linear foot of diffuser header pipe should be greater than 3 SCFM/linear ft. to ensure adequate aeration and mixing of tank contents.
- Adjust diffuser header valves to balance air distribution and to eliminate dead spots.
- Clean and check the diffusers. Diffusers should be cleaned on a routine basis to maintain good aeration performance. Generally every six months to one year.
- If fine bubble diffusers are extremely troublesome, consider replacing them with a coarse bubble type of diffuser. Coarse bubble diffusers require a greater air SCFM rate because of the reduced oxygen transfer efficiency; therefore, it must be determined that an adequate air supply is available before making this modification. Outside help should be obtained.
- Relocate and/or increase the number of diffusers (or mechanical aerators) to properly mix and aerate the tank contents.

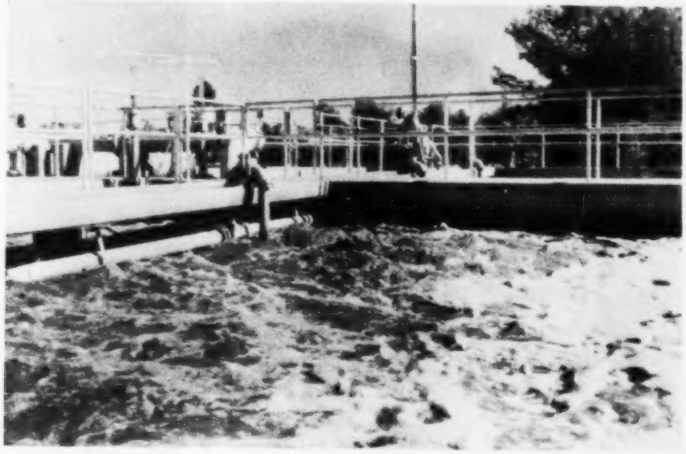
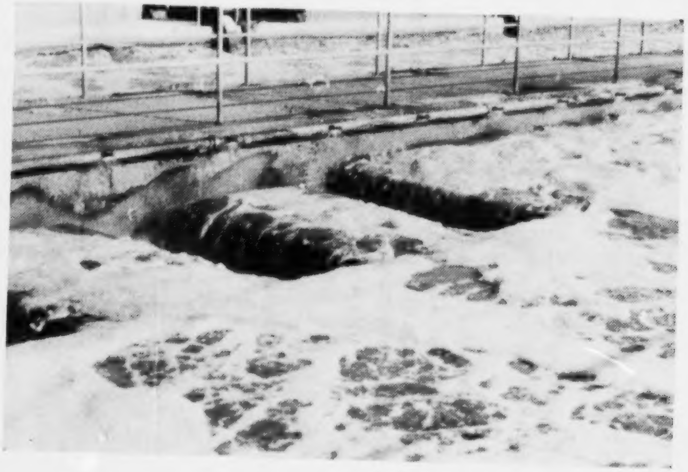
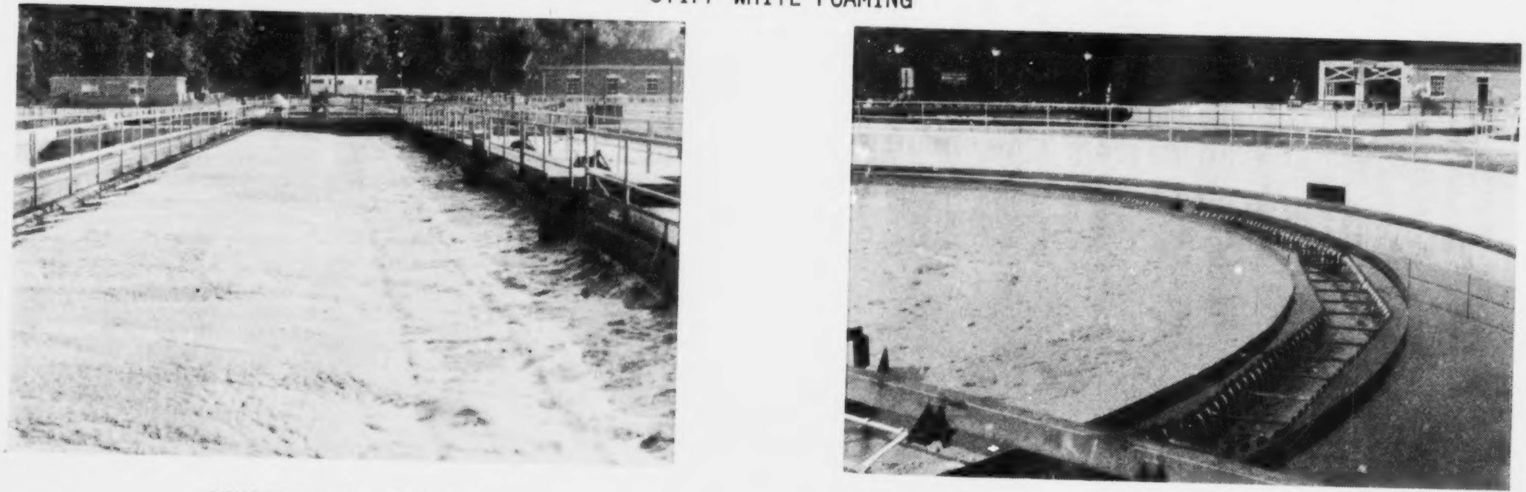


Figure II-13



STIFF WHITE FOAMING



GREASY BROWN FOAMING

CARRYOVER OF BROWN FOAM IN CLARIFIER

FOAMING PROBLEMS
FIGURE II-14

Foaming Problems (Refer to Figure II-14)

Minor foaming is normal in aeration tanks.

The presence of foam on the aeration tank is normal for the activated sludge process. Frequently, 10 to 25 percent of the aeration tank surface is covered with film or light froth or foam.

Two types of foaming conditions can occur.

Under certain operating conditions the foam (or froth) can become excessive and can affect operations. Two types of problem foam are normally seen. These are a thick brown greasy foam and a stiff white foam.

Foaming can create unsafe working conditions.

If the foam is allowed to build-up excessively, it can be blown by the wind onto walkways and plant structures, causing hazardous working conditions. In addition, it can create an unsightly appearance as well as cause possible odors. If the foam is carried over with the flow to the secondary clarifiers, it will tend to build-up behind the influent baffles and create additional cleaning problems.

Stiff White Foam

Causes for white foam.

The stiff white, billowing foam is indicative of an overloaded plant. This means that the MLSS concentration is too low and the F/M is consequently too high. The foam may consist of detergents or proteins which cannot be converted to food by the young and simple bacteria that grow in the MLSS at a high F/M.

Some probable causes of stiff white, billowing foam include the following:

1. Low MLSS due to process start-up.
2. Excessive wasting of activated sludge causing the MLSS concentration to drop too low for current organic loading.
3. The presence of unflavorable conditions such as toxic or inhibiting materials, abnormally low or high Ph's (pH below 6.5 or above 9.0), insufficient dissolved oxygen, nutrient deficiencies, or seasonal (summer to winter) wastewater temperature change resulting in reduced microorganism activity and growth.
4. Unintentional wasting of activated sludge in the effluent of the secondary clarifier. This condition could be caused by the following:
    - Excessive or shock plant loads.
    - Biological upset.
    - High sludge blanket in sludge clarifier.
    - Mechanical deficiencies in the clarifier.
    - Denitrification in the clarifier.
    - Improper distribution of flows or solids loadings to multiple clarifies.
5. Improper distribution of the wastewater and/or the RAS flows to multiple aeration tanks.

What are the corrective measures for white foaming.

The following applicable measures should be implemented to correct the foaming problem:

- Reduce the wasting of activated sludge to increase the MLSS concentration. Changes in the wasting rate should be made slowly and gradually (see Section 2.04 for waste activated sludge control methods and procedures).
- Maintain sufficient RAS rates to keep the sludge blanket in the lower half of the clarifier.
- Control the air SCFM rates to maintain D.O. levels of 1 to 3 mg/l in the aeration tank.
- Industrial waste ordinances must be actively enforced to avoid process upset and deterioration of the plant effluent.
- Modify the piping or structures as necessary to maintain the proper distribution (proportional to tank volumes) of flows to multiple aeration tanks and secondary clarifiers. The construction of some type of flow distribution structure may be required.

If flow meters are not provided, try these corrective measures.

If flow meters are not provided, compare the following measurements:

- The sludge blanket levels in each clarifier.
- The suspended matter concentration of each clarifier's RAS flow.
- The MLSS concentration in each aeration tank.

The corresponding measurements should be nearly equal if the wastewater, aeration effluent, and RAS flows are being properly distributed.

- If the aeration tanks are equipped with water sprays for froth control, operate the water sprays when there is danger of the foam being blown onto the walkways and/or other plant structures.

Excessive Brown Foam

Causes for brown foam.

This type of foam is associated with plants operating between the conventional and extended aeration loading ranges. Nitrification and filamentous organisms such as Nocardia are often associated with this type of foam. The thick brown greasy foam is normal at any plant that practices sludge reaeration. The appearance of this type of foam can result in additional problems in the clarifier by building up behind the influent baffles and creating a scum disposal problem as shown in Figure II-14. Scum containing filamentous organisms should not be returned to the aeration tanks. Some probable causes of the foaming problem are as follows:

1. Aeration tank is being operated at a low F/M ratio because nitrification is required by regulatory agency.
2. Build-up of a high MLSS concentration due to insufficient sludge wasting. This condition could untentionally occur when the seasonal (winter to summer) wastewater temperature change results in greater activity of the microorganism and consequently greater sludge production.
3. Operating in the sludge reaeration mode. A thick brown foam is normal in the sludge reaeration tank.
4. Improper WAS control program. See Section 2.04, "PROCESS CONTROL."

What are the corrective measures for brown foaming.

The following applicable measures should be implemented to correct the foaming problem:

- If nitrification is not required, gradually increase the wasting rate to increase the F/M ratio (see Section 2.04, "PROCESS CONTROL"). If the scum is not returned to the aeration tanks, include the volatile solids removed in the scum in the waste sludge calculations. During normal operation, the amount of volatile solids removed with the scum is too small to matter. However, during heavy foaming, as much as 10 percent of the waste activated sludge solids may be removed with the scum.
- When filaments appear in a nitrifying sludge, they may be killed by the addition of chlorine to the RAS. Recent experiences suggests that the does of chlorine required will be from 2 to 3 lb Cl_2/1000 lbs of MLVSS/day.
  CAUTION: Excessive chlorination can harm the desirable micro-organisms.
- Implement a better program for controlling the waste of activated sludge. Read Section 2.04 "PROCESS CONTROL" for more guidance on waste activated sludge control techniques.

Solids Washout (See Case 1 on Figure II-16)

Settleability test helps to identify solids washout problem.

This condition can sometimes be quickly detected when good settling is observed in the 30-minute settling test but billowing homogenous sludge solids are rising in the secondary clarifier (Figure II-15) even though the sludge blanket is in the lower half of the clarifier.

What are causes for solids washout?

Some probable causes of solids washout are as follows:

1. Equipment malfunction
2. Hydraulic overload
3. Solids overload
4. Temperature currents

The following applicable measures should be implemented to correct the solids washout problem:

Equipment Malfunction

Is the clarifier working properly?

The operator should inspect all equipment in the clarifier to ensure that it is operating properly. Specifically check the following:

- Sludge Collection Equipment —
  - Look for broken drives or support members.
  - Look for uneven blanket depth at several locations in the clarifier. An uneven blanket may indicate a plugged suction collector or broken plough.

- Baffles and Skirts —
  - Look for broken welds, bolts, or supports.
  - Look for holes in the baffle.
- Weir Levels —
  - Look for unbalanced flow over the weirs. Are the weirs on one side of the tank more deeply covered than those on the other side? The weirs should be adjusted to an equal elevation.

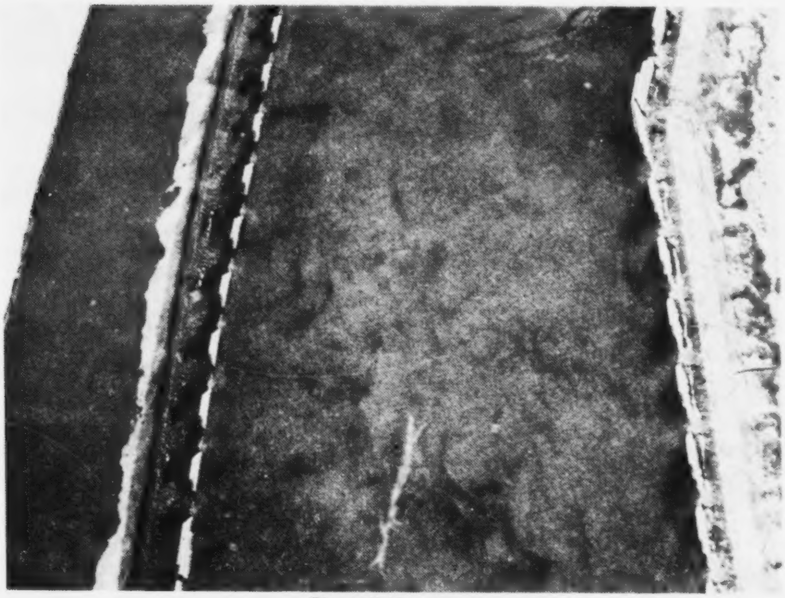


Figure II-15

Hydraulic Overload

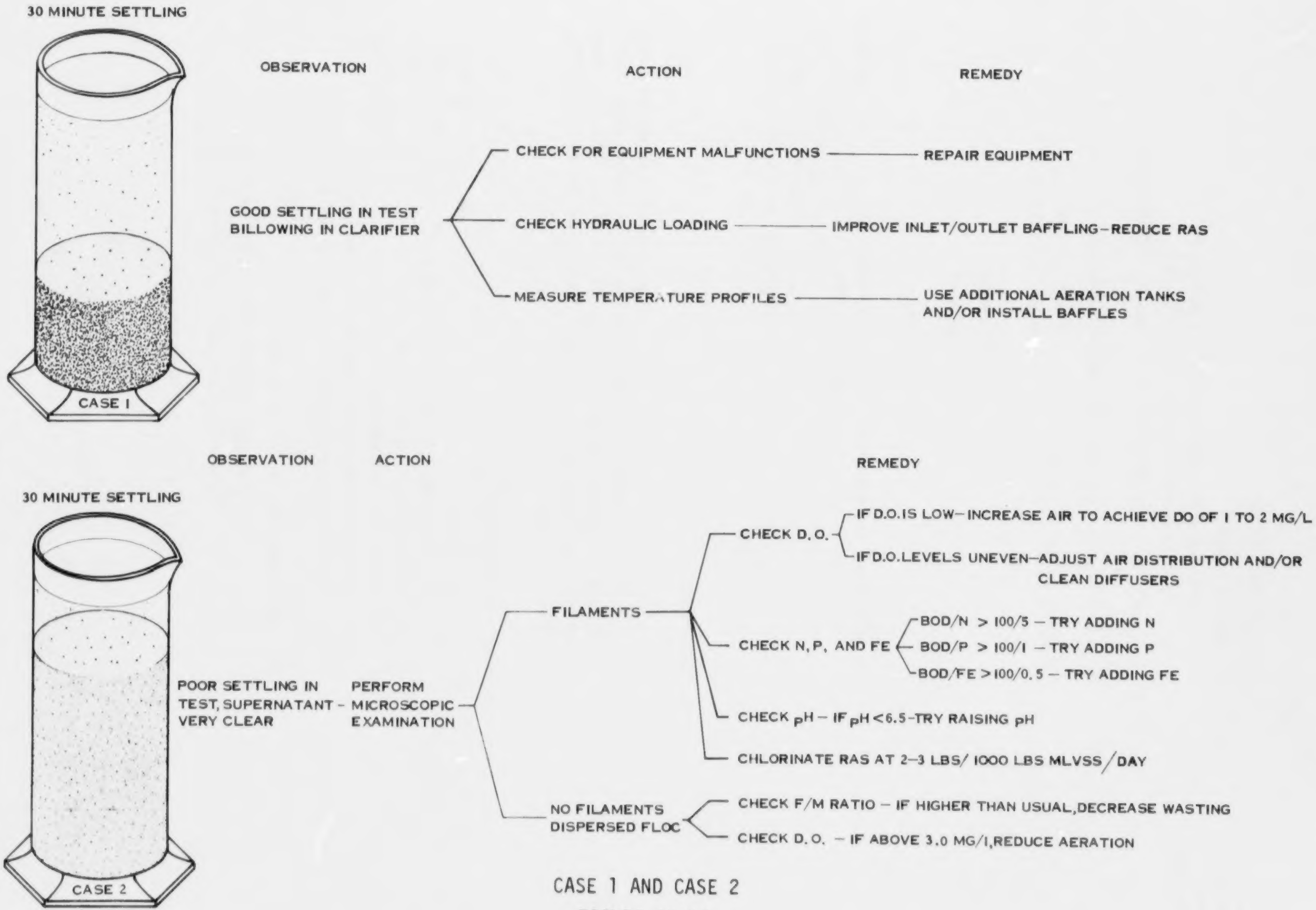
The operator should check the hydraulic loading on each clarifier by either measuring the flow to each clarifier or by estimating the flow balance between multiple units as indicated by the depth of flow over the weirs in each of the clarifiers. Overloading can result from excessive flow or unevenly distributed flow between multiple units. Approach and solve the problem as follows:

Are the flows balanced between multiple units?

- Determine if the flows are being distributed equally to the aeration basins and clarifier units. The weirs at the effluent end of the aeration tanks must be adjusted to an equal elevation to provide an equal distribution of loading to each tank. The weirs or gates at the RAS distribution structures must be adjusted to an equal elevation to provide proper distribution of RAS flows. The weirs at the secondary clarifier distribution structures must be adjusted to an equal elevation to provide a uniform hydraulic loading. In addition, the effluent weirs must be ajusted to an equal elevation to provide optimum clarifier performance.

Check the clarifier surface overflow rate.

- After checking and correcting the weir elevations where needed, determine the clarifier surface overflow rate as follows:


30 MINUTE SETTLING
OBSERVATION
ACTION
REMEDY
CASE I
GOOD SETTLING IN TEST BILLOWING IN CLARIFIER
CHECK FOR EQUIPMENT MALFUNCTIONS
REPAIR EQUIPMENT
CHECK HYDRAULIC LOADING
IMPROVE INLET/OUTLET BAFFLING–REDUCE RAS
MEASURE TEMPERATURE PROFILES
USE ADDITIONAL AERATION TANKS AND/OR INSTALL BAFFLES
OBSERVATION
ACTION
REMEDY
30 MINUTE SETTLING
CASE 2
POOR SETTLING IN TEST, SUPERNATANT VERY CLEAR
PERFORM MICROSCOPIC EXAMINATION
FILAMENTS
CHECK D.O.
IF D.O. IS LOW–INCREASE AIR TO ACHIEVE DO OF 1 TO 2 MG/L
IF D.O. LEVELS UNEVEN–ADJUST AIR DISTRIBUTION AND/OR CLEAN DIFFUSERS
CHECK N, P, AND FE
BOD/N > 100/5 – TRY ADDING N
BOD/P > 100/1 – TRY ADDING P
BOD/FE > 100/0.5 – TRY ADDING FE
CHECK pH – IF pH < 6.5–TRY RAISING pH
CHLORINATE RAS AT 2–3 LBS/ 1000 LBS MLVSS/DAY
NO FILAMENTS DISPERSED FLOC
CHECK F/M RATIO – IF HIGHER THAN USUAL, DECREASE WASTING
CHECK D.O. – IF ABOVE 3.0 MG/l, REDUCE AERATION

CASE 1 AND CASE 2

FIGURE II-16

How to calculate clarifier overflow rate.

Example Calculation

A. Data Required
   1. Surface area, each clarifier = 7,850 sq. ft.
   2. Two clarifiers, total area = 15,700 sq. ft.
   3. Plant flow (peak hour) = 7.5 mgd or 7,500,000 gpd

B. Determine the clarifier surface overflow rate.

$$\text{Surface overflow rate, gpd/ft.}^2 = \frac{\text{Plant flow, gpd}}{\text{Clarifier surface area, sq. ft.}}$$

$$= \frac{7{,}500{,}000\ \text{gpd}}{15{,}700\ \text{sq. ft.}}$$

$$= 478\ \text{gpd/sq. ft.}$$

C. Compare the calculated surface overflow rate with the design rate. If the current rate exceeds the design rate (see Section 2.03, "SECONDARY CLARIFIERS"), the clarifiers are hydraulically overloaded, and additional clarifier units are required in operation. If all clarifiers are operating, plant expansion or flow equalization is required.

Solids Overload

Check the clarifier solids loading.

A special case of overloading of the clarifier is known as solids overloading. Solids overloading is related to the Q, RAS flow, and MLSS concentration. Reducing the MLSS concentration or the RAS flow may eliminate the poor settling in the clarifier. Determine the solids loading rate as follows:

How to calculate clarifier solids loading rate.

Example Calculation

A. Data Required
   1. Surface area, each clarifier = 7,850 sq. ft.
   2. Two clarifiers, total = 15,700 sq. ft.
   3. Plant flow, Q (peak hour) = 7.5 mgd
   4. Q_{RAS}, RAS flow rate (peak hour) = 3.8 mgd
   5. Aeration effluent MLSS, peak hour = 2,500 mg/l

B. Calculate the solids loading rate.

$$\text{lb/ft}^2\text{/hr} = \frac{(Q + Q_{RAS}\text{, mgd})\ (\text{MLSS, mg/l})\ (8.34\ \text{lbs/gal})}{(24\ \text{hrs/day})\ (\text{Clarifier surface area, sq. ft.})}$$

$$= \frac{(7.5 + 3.8)\ (2{,}500)\ (.8.34)}{(24)\ (15{,}700)}$$

$$= 0.63\ \text{lb MLSS/sq. ft./hr}$$

C. A solids loading rate value of 1.25 lb/sq. ft./hr is a practical upper limit for clarifier operation. If the calculated value for a particular plant exceeds this value the following approaches should be tried.
   - Utilize any available aeration tank or clarifiers.
   - Reduce the RAS flow.
   - Reduce the MLSS concentration.

Are all available tanks in operation?

The use of all available aeration tanks makes it possible to reduce the MLSS concentration without changing the F/M. The extra volume of additional aeration tank makes it possible to have the same volatile solids inventory with a lower MLSS concentration, which effectively reduces the solids loading rate.

Allow solids to build in clarifier during peak flow period.

Decrease the solids inventory.

If no additional aeration tanks are available, the second approach should be used. The RAS flow should be reduced by 10 to 20 percent. The depth of the sludge blanket in the clarifiers should be measured periodically to ensure the sludge blanket does not build to an excessive depth. Observe the clarifier to see if the poor settling characteristics are improved. If the settling does not improve after reducing the RAS flow, the MLSS should be decreased by slightly increasing the wasting rate. Be aware that the F/M is increasing during this procedure because the solids inventory will decrease. A practical limit for MLSS reduction would be a 10 percent gradual change in one week. If no improvement occurs during these adjustments, the high effluent suspended solids concentrations are most likely not due to solids overloading.

Temperature Currents

How to conduct a temperature profile.

A temperature profile of the clarifier will identify the presence of any temperature currents. The temperature probe on a dissolved oxygen meter is an excellent tool for this procedure. To make the profile, the temperature is measured and recorded at the head, one quarter, one half, three quarters and tail end of a rectangular or square clarifier, or at the quarter points across a circular clarifier. At each point, the temperature is measured at the surface and the quarter points down to the bottom of the tank. Be careful that the temperature probe and wires do not get entangled in the sludge collection equipment.

Install baffles.

If the deeper temperatures are consistently cooler by 1 to 2° C or more, temperature currents are present. The settling may be improved if baffles are installed to break up the currents and stop the turbulence.

Bulking Sludge (See Case 2 on Figure II-16)

Poor settling and compaction, with a clear supernatant.

The presence of a clear supernatant above a poor settling sludge indicates that the settling is being hindered by either the presence of filamentous microorganisms or dispersed floc. The presence of filamentous microorganisms is corrected by improving the treatment environment with the addition of nutrients, such as nitrogen and phosphorous, and/or by correcting the dissolved oxygen concentration in the aeration tank. The presence of dispersed floc indicates either organic overloading or overaeration. Classic sludge bulking in the clarifier is illustrated in Figure II-17.

Some probable causes of the bulky sludge problem are as follows:

1. Filamentous microorganisms present
    - Low D.O. in aeration tank
    - Insufficient nutrients
    - Low pH
    - Warm wastewater temperature
    - Industrial wastes
2. No filamentous microorganisms present
    - Organic overloading (high F/M)
    - Overaeration

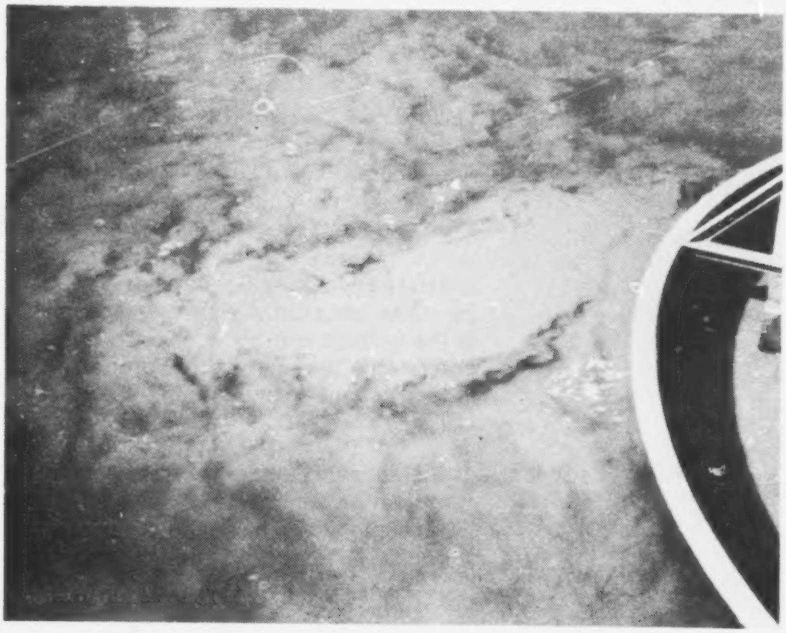


Figure II-17

Determine if filamentous organisms are present.

The first step in analyzing this condition is to perform a microscopic examination of the MLSS. Microscopic analysis of the MLSS is described in Section IV, "LABORATORY CONTROL." Approach and solve the problem as follows:

Filamentous Microorganisms Present (Figure II-18)

What to check when filamentous organisms are present.

If filamentous microorganisms are present, the following steps should be followed:

- Measure the D.O. level at various locations throughout the aeration tank.

  If the average D.O. is less than 0.5 mg/l there is insufficient dissolved oxygen in the aeration tank. Solution - Increase the air SCFM rate until the D.O. levels increase to 1 to 3 mg/l throughout the tank.

  If the D.O. levels are nearly zero in some parts of the basin, but are higher in other locations, the air distribution system is out of balance or the diffusers in an area of the basin may need to be cleaned. Solution - Balance air system and/or clean diffusers.
- Calculate the ratios of BOD to nitrogen (use TKN expressed as N), BOD to phosphorus (expressed as P), and BOD to iron (expressed as Fe). In general, anhydrous ammonia is used to add N, trisodium phosphate is used to add P, and ferric chloride is used to add Fe.

Example Calculation

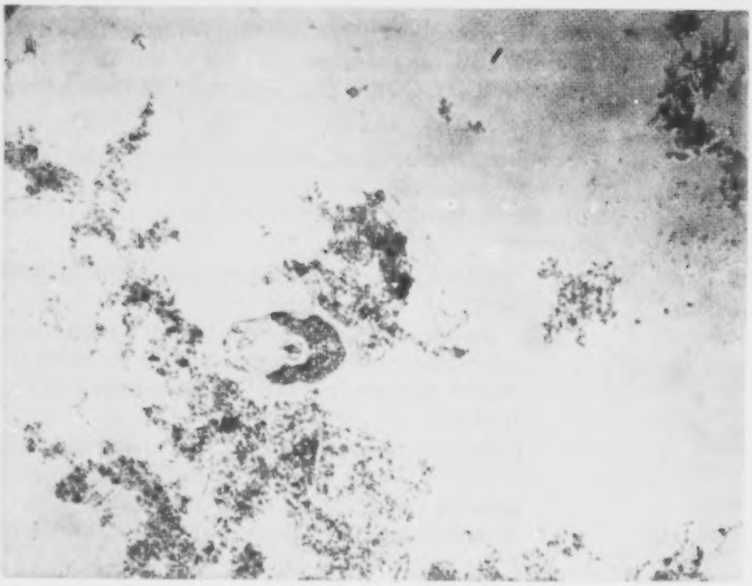
How to calculate amount of nutrients to use.

A. Data Required

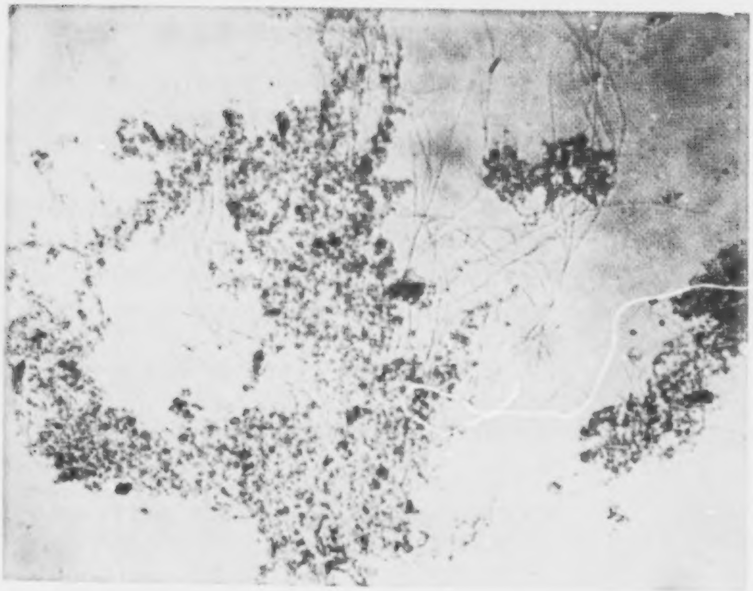
1. Influent BOD = 170 mg/l
2. Influent TKN = 4.5 mg/l
3. Suggested ratio, BOD/N = 100/5 = 20
4. Suggested ratio, BOD/P = 100/1 = 100
5. Suggested ratio, BOD/Fe = 100/0.5 = 200
6. Plant Q, average daily = 7.5 mgd
7. Ammonia/nitrogen atomic weight ratio, NH_3/N = 17/14 = 1.2
8. Trisodium phosphate/phosphorus atomic weight ratio, Na_3PO_4/P = 164/31 = 5.3
9. Phosphroic acid/phosphorus atomic weight ratio, H_3PO_4/P = 98/31 = 3.16
10. Ferric chloride/iron atomic weight ratio, $FeCl_3/fe$ = 162.5/56 = 2.9

B. Calculate the amount of N,P, and Fe needed per day to achieve the suggested ratios.

$$\text{Nutrient needed} = \frac{\text{BOD, mg/l}}{\text{Respective suggested ratio from 3, 4 or 5 above}}$$



GOOD SETTLING SLUDGE



FILAMENTOUS ORGANISMS IN BULKING SLUDGE

MICROSCOPIC OBSERVATIONS
FIGURE II-18

Example Calculation

$$\text{N needed} = \frac{\text{BOD, mg/l}}{\text{Suggested ratio, BOD/N}}$$

$$= \frac{170}{20}$$

$$= 8.5 \text{ mg/l}$$

C. Calculate the difference between the nutrient available and the nutrient needed.

Nutrient shortage = N needed - Nutrient available

Example Calculation

N shortage = N needed - TKN available

= 8.5 - 4.5

= 4.0 mg/l*

*Nutrient addition is not needed when answer is zero.

D. Calculate the pounds of nutrients that need to be added per day.

Nutrient, lbs/day = (N shortage, mg/l) (Q, mgd) (8.34 lbs/gal)

Example Calculation

Nitrogen, lbs/day = (N shortage, mg/l) (Q, mgd) (8.34 lbs/gal)

= (4 mg/l) (7.5 mgd) (8.34 lbs/gal)

= 250 lbs of N/day

E. Calculate the pounds of the respective commercial chemical to be added per day.

$$\text{Chemical, lbs/day} = \frac{(\text{Nutrient lbs/day})(\text{Respective atomic wt. ratio})}{\text{Concentration of chemical, \%}}$$

Example Calculation

$$\text{Anhydrous ammonia} = \frac{(\text{N, lbs/day})(1.2\ NH_3/N)}{NH_3\ \text{concentration, \%}}$$

(assume using a commercial grade with a 80% conc.)

$$= \frac{(250\ \text{lbs/day})(1.2\ NH_3/N)}{80\%}$$

$$= \frac{300}{0.8}$$

= 375 lbs of anhydrous ammonia needed/day

Addition of nutrients.

Nutrients should be added at the influent end of the aeration tank. The settleability of the sludge should be carefully observed to see if it is improving. If the settleability improves, the dose of nutrient can be reduced by five percent per week until the settleability begins to decrease. Then increase the dose by five percent and observe the settleability.

Nutrients should be applied with care.

Nutrients are expensive and they should be applied with care. Nutrient dosage may be increased with increased BOD concentrations which takes into account the effects of the additional microorganism growth that will occur. If the settleability does not improve readily, the nutrient dosing should be continued until the actual problem is identified and solved, because the problems that are causing the poor settleability may be interrelated.

Is the aeration tank pH 6.5.

Prevent problem at source.

If the pH in the aeration tank is less than about 6.5, the settleability of the sludge may be affected due to inhibition of the bacteria that settle readily. If the pH of the raw wastewater is less than 6.5, the low pH problem is probably due to industrial wastes and a survey should be conducted to identify the industry that is in violation of its discharge permit. The best procedure, if possible, is to prevent the problem by control at the source. A good industrial waste monitoring and enforcement program will avoid many difficulties in this area.

Effect of nitrification.

Nitrification destroys alkalinity and reduces the aeration pH level. If this is the cause of the problem, raise the MLSS pH by adding caustic soda or lime at the influent end of the aeration tank. If nitrification is required, it is suggested that the MLSS pH be maintained in the range of 7.2 to 7.8 to encourage an acceptable rate of nitrification. Care must be exercised to ensure that the treatment system is not shocked by high pH levels or overdosed to pH levels above 9.

Determining amount of caustic required.

The best method for determining the amount of caustic required to raise the pH involves a batch titration technique. A solution containing a known concentration of caustic is added dropwise to a sample of MLSS. The sample volume must be known and the sample must be stirred during this determination. The dropwise addition of caustic is continued until the pH is approximately 7.2. The amount of caustic added is proportional to the amount required to raise the pH in the treatment system. The pounds of caustic soda (NaOH) required is determined as follows:

How to calculate caustic needed.

Example Calculation

A. Data Required

1. Plant Q average daily = 7.5 mgd
2. Normality of NaOH used in titration = 0.02N
3. Volume of NaOH used to titrate sample = 6.5 ml
4. Equivalent weight of 1.0 N NaOH (one liter) = 40,000 mg/l
5. Concentration of commercial caustic soda solution used = 25%
6. Volume of sample titrated = 1 liter

B. Determine the mg/l of pure NaOH needed to raise the sample pH to about 7.2.

NaOH needed, =
mg/l
(pure NaOH)

$$\frac{(\text{ml of NaOH used, liter sample volume})(\text{Normality of NaOH})(\text{Equivalent wt})}{1000\text{ ml/l}}$$

$$= \frac{(6.5\text{ ml})(0.02\text{ N})(40{,}000\text{ mg/l})}{1000\text{ ml/l}}$$

$$= 5.2$$

C. Determine the lbs/day of pure NaOH needed to adjust the pH of the activated sludge.

NaOH needed, lbs/day = (NaOH needed, mg/l) (Q, mgd) (8.34 lbs/gal)
(pure NaOH)

= (5.2 mg/l) (7.5 mgd) (8.34 lbs/gal)

= 325.26

D. Determine the lbs/day of commercial caustic soda solution needed. Caustic soda is frequently used as a 25 percent by weight solution.

$$25\%\ \text{NaOH solution, lbs/day} = \frac{(\text{lbs of pure chemical needed/day})(100\%)}{\text{Solution concentration }\%}$$

$$= \frac{(325.2\ \text{lbs/day})(100\%)}{25\%}$$

$$= 1301$$

Determining the amount of lime required.

When determining the amount of lime needed for pH adjustment, obtain and weigh a small amount (about 1 or 2 grams) of the actual lime to be used in the treatment process. While a measured sample is stirring, add small increments of the weighed lime (or suspension) until the pH is about 7.2. Then, weigh (or measure) that portion of the lime (or suspension) not used to determine the amount of lime used in the titration. The pounds of lime required is determined as follows:

How to calculate lime needed.

Example Calculation

A. Data Required
   1. Plant Q, average daily = 7.5 mgd
   2. Weight of lime before titration = 1.0100 grams
   3. Weight of lime after titration = 1.0056 grams
   4. Weight of lime used in titration = 0.0044 grams
   5. Volume of sample titrated = 1000 ml

B. Determine the mg/l of lime needed to raise the sample pH to about 7.2.

$$\text{Lime needed, mg/l} = \frac{(\text{Sample vol. ml})(\text{lime used, g})(1000\ \text{mg/g})}{1000\ \text{ml/l}}$$

$$= \frac{(1000\ \text{ml})(0.0044\text{g})(1000\ \text{mg/g})}{1000\ \text{ml/l}}$$

$$= 4.4$$

C. Determine the lbs/day of lime needed to adjust the pH.

$$\text{Lime needed, lbs/day} = (\text{Lime needed, mg/l})(Q,\ \text{mgd})(8.34\ \text{lbs/gal})$$

$$= (4.4\ \text{mg/l})(7.5\ \text{mgd})(8.34\ \text{lbs/gal})$$

$$= 275$$

Is the chemical addition effective?

The addition of lime or caustic to raise the pH is an expensive operation. The settleability of the sludge should be closely monitored to observe changes to ensure that benefit is being gained from the addition of caustic or lime. If no improvement in settleability occurs within a 2 to 4 week period, then the addition of caustic or lime should be halted.

Addition of oxidizing agents.

The chlorination of the RAS is a dependable and effective control of filamentous microorganisms. The filamentous microorganisms are more readily affected by the addition of oxidizing agents such as chlorine because they have a greater surface area to volume ratio. The addition of other oxidizing agents such as hydrogen peroxide in dosages of 100 to 200 mg/l has also been reported to effectively control the presence of filamentous microorganisms.

Treats the symptoms—*not* the cause.

The use of oxidizing agents does not treat the cause of the problem but only treats the symptoms. The most cost-effective solutions to the problems relating to filamentous microorganisms will involve treating the cause of the problem, such as adding nutrients or increasing aeration, and not the symptoms.

Determining the amount of Cl_2 required.

A dose of 2-3 lbs of Cl_2 per 1000 lbs of MLVSS per day has been reported to effectively control filamentous microorganisms. The chlorine dosage is expressed in the form of a ratio, which is a logical and useful approach to chemical dosing in activated sludge systems. The proper chlorine feed rate is determined as follows:

Example Calculation

How to calculate Cl_2 feed rate.

A. Data Required
   1. Aeration MLVSS = 2000 mg/l
   2. Aeration volume = 1.26 mil gal
   3. Desired Cl_2 dosage lbs/1000 lbs MLVSS/day = 2.5 lbs

B. Calculate the volatile solids inventory under aeration.

$$\text{MLVSS, lbs} = (\text{MLVSS, mg/l})(\text{Aer. vol., mg})(8.34\ \text{lbs/gal})$$

$$= (2000\ \text{mg/l})(1.26\ \text{mg})(8.34\ \text{lbs/gal})$$

$$= 21{,}017\ \text{lbs of MLVSS}$$

C. Calculate the chlorine feed rate.

$$Cl_2\text{, lbs/day} = \frac{(Cl_2\ \text{dosage})(\text{MLVSS, lbs})}{1000}$$

$$= \frac{(2.5\ \text{lbs}\ Cl_2\ (21{,}017\ \text{lbs of MLVSS})}{1000\ \text{lbs MLVSS}}$$

$$= 52.5\ \text{lbs}\ Cl_2\text{/day}$$

Outside help may be needed.

If filamentous bulking is occurring quite often, it is recommended that the operator have an experienced microbiologist identify the type of filamentous organism causing the problem. After identifying the type of organism, the microbiologist can provide data on the type and/or source of the waste contribution to the growth of this organism. For instance, if the filamentous organisms were identified as Toxothrix, a condition promoting the production of sulfides (H_2S) such as septicity in the collection system or treatment plant is the probable cause. With this type of insight into the problem, the operator can implement the appropriate measures to reduce the number of future problems. In addition, the operator will be better informed on how to handle the problem the next time it occurs.

No Filamentous Microorganisms Present

Is the F/M normal?

Check the F/M to determine if the system is operating at a higher F/M value than is normally used. The presence of small dispersed flocs is characteristic of an increased F/M. If the F/M is higher than normal by 10 percent or more the wasting rate should be decreased. The decrease in the F/M should be reflected by the disappearance of the dispersed flocs over a period of a week.

D.O. concentration is important.

The amount of turbulance and D.O. in the aeration tank is also important. D.O. concentrations above 3.0 mg/l indicate that excess air is being used, and the aeration rate should be reduced to lower the D.O. concentrations to the range of 1 to 3 mg/l. Excessive turbulance (overaeration) in the aeration tank will hinder MLSS floc formation and may result in the carryover of pinpoint floc with the clarifier effluent.

Clumping/Rising Sludge (See Case 3 on Figure II-20)

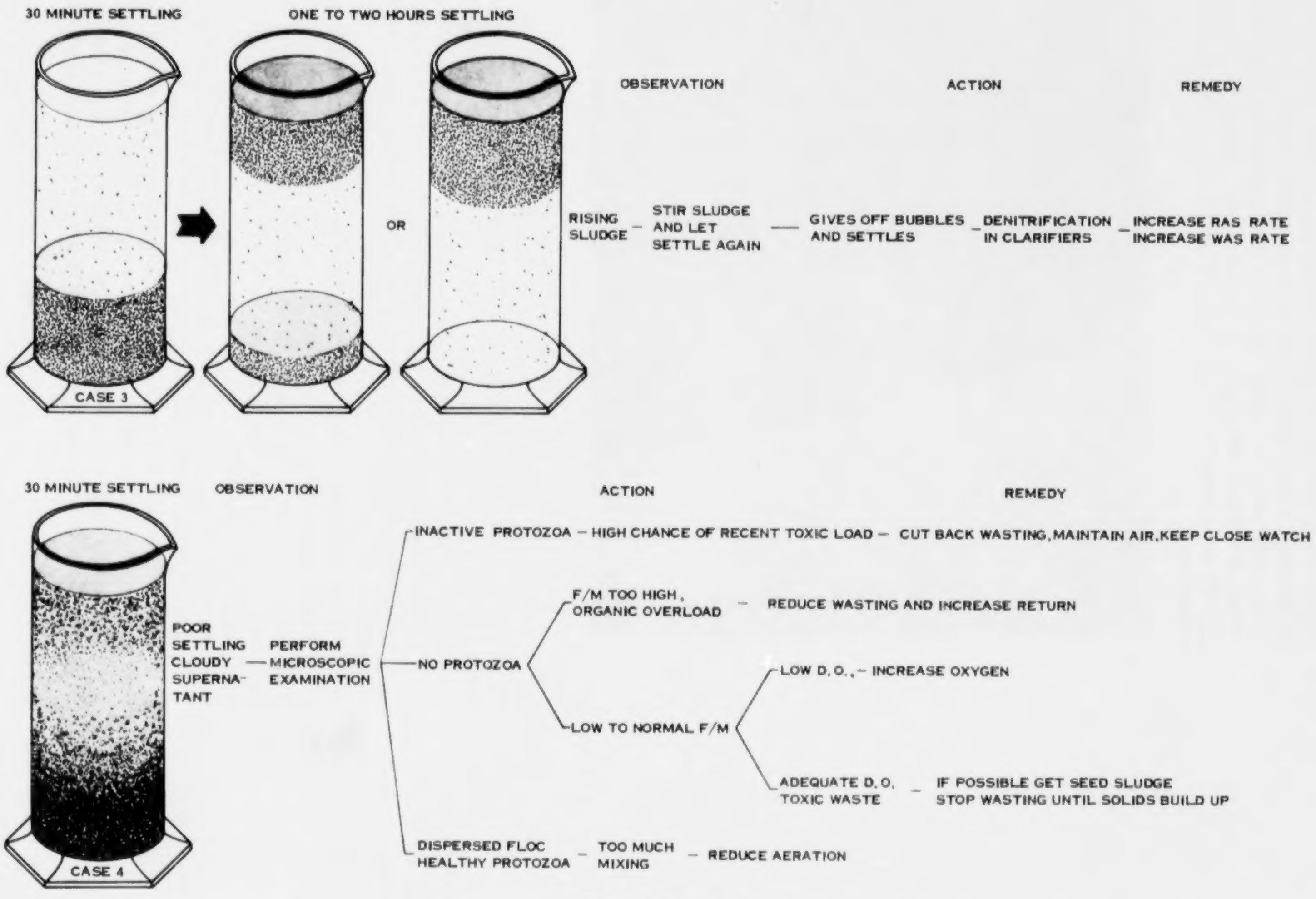
Result of dentrification.

When the sludge initially settles during the 30-minute settling test and then floats to the surface after one to two hours, the problem is generally that denitrification is occurring in the clarifier, as illustrated in Figure II-19. Nitrate ions are reduced to nitrogen gas and bubbles are formed in the MLSS floc as a result of this process. The bubbles attach to the biological flocs and float the flocs to the surface of the clarifier where they eventually flow over the weir.

Causes of clumping and rising.

Some probable causes of sludge clumping:

1. The activated sludge process is being operated at a low F/M ratio and consequently the process has "slipped" slightly or completely into the nitrification zone.
2. The sludge is being held too long in the clarifier and consequently all the available dissolved oxygen has been used by the microorganisms. The return sludge should have a D.O. content of not less than 0.2 mg/l.


30 MINUTE SETTLING
ONE TO TWO HOURS SETTLING
OR
CASE 3
OBSERVATION
ACTION
REMEDY
RISING SLUDGE
STIR SLUDGE AND LET SETTLE AGAIN
GIVES OFF BUBBLES AND SETTLES
DENITRIFICATION IN CLARIFIERS
INCREASE RAS RATE
INCREASE WAS RATE
30 MINUTE SETTLING
CASE 4
OBSERVATION
ACTION
REMEDY
POOR SETTLING CLOUDY SUPERNATANT
PERFORM MICROSCOPIC EXAMINATION
INACTIVE PROTOZOA
HIGH CHANCE OF RECENT TOXIC LOAD
CUT BACK WASTING, MAINTAIN AIR, KEEP CLOSE WATCH
NO PROTOZOA
F/M TOO HIGH, ORGANIC OVERLOAD
REDUCE WASTING AND INCREASE RETURN
LOW TO NORMAL F/M
LOW D.O.
INCREASE OXYGEN
ADEQUATE D.O. TOXIC WASTE
IF POSSIBLE GET SEED SLUDGE
STOP WASTING UNTIL SOLIDS BUILD UP
DISPERSED FLOC HEALTHY PROTOZOA
TOO MUCH MIXING
REDUCE AERATION

CASE 3 AND CASE 4
FIGURE II-20

3. Higher than normal wastewater temperature resulting in a higher rate of microorganism activity which causes the process to nitrify at a higher F/M ratio. A higher rate of microorganism activity will also result in a faster depletion of the dissolved oxygen in the clarifier sludge and consequently a greater potential for septicity and denitrification.

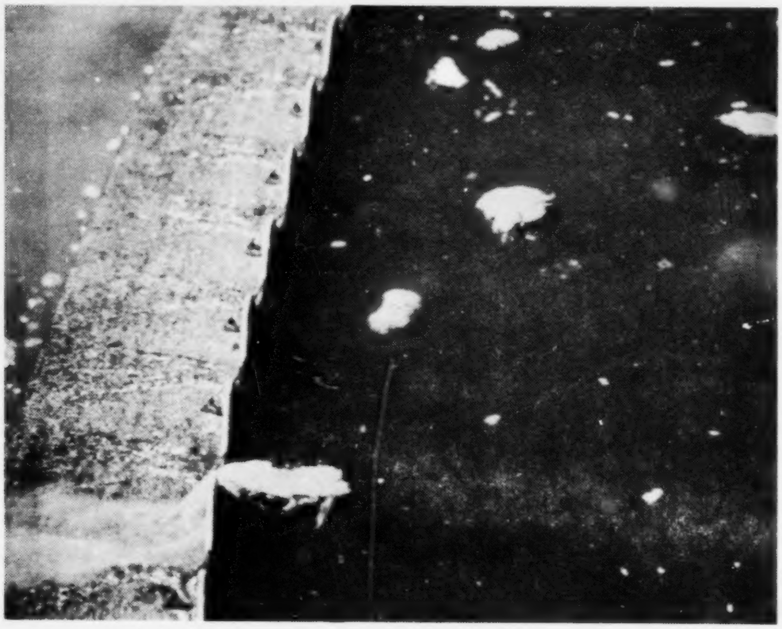


Figure II-19
Clumping In Clarifier

The following applicable measures should be implemented to correct the sludge clumping problem:

Corrective measures for sludge clumping.

- Increase the return activated sludge flow rate to reduce the detention time of the sludge in the clarifiers. A periodic measurement of the clarifier sludge blanket depth will help to determine the proper return rate.
- Where possible, increasing the speed of the sludge collector may lessen the problem.
- When the suction type of sludge collector is employed, check that all suction tubes are flowing freely with a fairly consistent suspended solids concentration. Some of the suction tubes may be improperly adjusted or plugged resulting in coning in some areas and a sludge blanket build-up in other areas.
- If nitrification is not required, gradually increase the sludge wasting rate to stop nitrification. Initially, the solids inventory should be decreased by 10 percent over one week, and then the process operation must be observed over the following two weeks to see if treatment has improved.

Cloudy Secondary Effluent (See Case 4 on Figure II-20)

Perform the 30-minute settling test.

During the periods of high effluent suspended solids concentration, the settleability (or settling) test should be run immediately and followed up with additional tests several times a day until the problem is identified and corrected. When the mixed liquor in the settleability test settles poorly leaving a cloudy supernatant, the next step is to perform a microscopic examination of the mixed liquor. One of the important purposes of this examination is to determine if protozoa are present and the status of their health. The use of a microscope for process control and troubleshooting is further described in Section IV, "LABORATORY CONTROL."

Protozoa Are Present

Protozoa appear inactive.

If protozoa are present, their actions and appearance should be observed. When the protozoa appear to be inactive it frequently indicates that a slug of toxic material has recently entered the treatment system. The operator should reduce the sludge wasting rate and maintain normal operation until the material passes through the treatment system. Refer to Table II-12.

Protozoa are active.

If the protozoa appear normal and active, but the cloudy condition persists, the activated sludge floc may be dispersed due to excessive turbulence (overaeration) in the aeration tank. Generally, overaeration is characterized by D.O. concentrations above 3 mg/l in the aeration tank. Proper control of the aeration system is further described in Section 2.04, "AERATION AND D.O. CONTROL."

Protozoa Are Not Present

No protozoa present.

What to check.

If no protozoa are present, there are two possibilities. First, the F/M is too high and the system is operating in an overloaded manner. Approach and solve the problem as follows:

- Calculate the F/M. Refer to Section 2.04, Constant F/M Control.
- Compare calculated F/M with F/M's for the periods of satisfactory operation.
- If the F/M is greater than these values, the wasting rate should be reduced to raise the solids inventory.
- Increase the RAS flow to lower the sludge blanket level in the clarifier to the minimum. The increased RAS flow will increase the solids inventory by transferring the MLSS stored in the clarifier into the aeration tank.

Second, the F/M may be lower than or within the normal range. This condition is frequently associated with one of the following:

- Low D.O. concentration in the aeration tank. If the average D.O. measured at several locations in the aeration tank is less than 0.5 mg/l, aeration should be increased until the D.O. is between 1 and 3 mg/l.

Ash-like solids floating on clarifier surface.

- A toxic waste entered the treatment system. Toxic waste adversely affects the health of the activated sludge. A short term solution to this problem involves the addition of large quantities of healthy seed sludge to build-up the volatile solids inventory. The long term solution requires an industrial waste survey to identify the source of the toxic material and the enforcement of strict industrial waste discharge ordinances. Table II-12 shows the levels of heavy metals that can usually be tolerated by activated sludge microorganisms on both a long-term and short-term basis.

TABLE II-12

ALLOWABLE CONCENTRATIONS OF HEAVY METALS

	CONCENTRATION AT WHICH DAMAGE TO ACTIVATED SLUDGE MIGHT OCCUR	
CONSTITUENT	CONTINUOUS LOADING	SLUG LOADING
CADMIUM	1 mg/l	10 mg/l
CHROMIUM	2 mg/l	2 mg/l
COPPER	1 mg/l	1.5 mg/l
IRON	35 mg/l	100 mg/l
LEAD	1 mg/l	—
MANGANESE	1 mg/l	—
MERCURY	0.002 mg/l	0.5 mg/l
NICKEL	1 mg/l	5 mg/l
SILVER	0.03 mg/l	0.25 mg/l
ZINC	1 to 5 mg/l	25 mg/l
COBALT	>1 mg/l	
CYANIDE	1 mg/l	1 to 10 mg/l
ARSENIC	0.7 mg/l	

Ashing (See Case 5 on Figure II-22)

The appearance of small ash-like sludge particles floating on the surface of the secondary carifier (Figure II-21) is commonly referred to as "ashing."

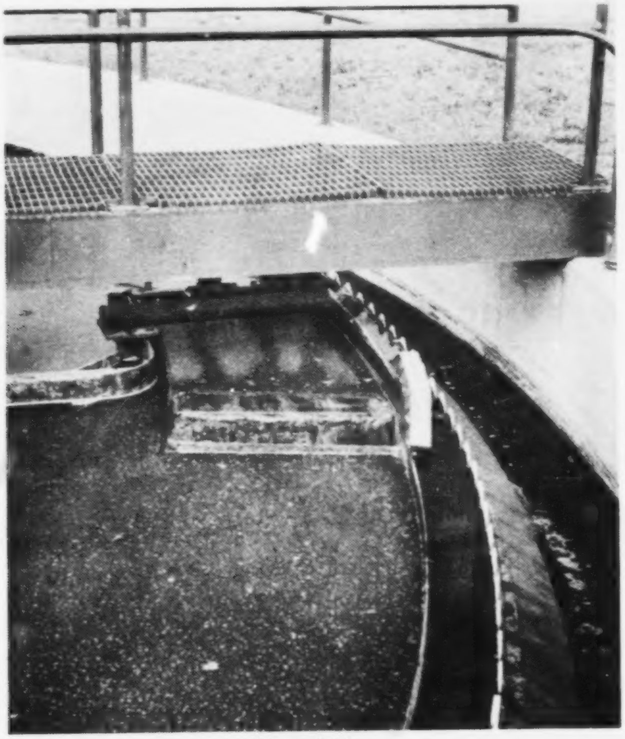


Figure II-21
Ashing In Clarifier

Causes of ashing.

Some probable causes of the ashing problem are as follows:

1. The beginning of denitrification is occurring in the clarifier.
2. The mixed liquor has an unusually high grease content.

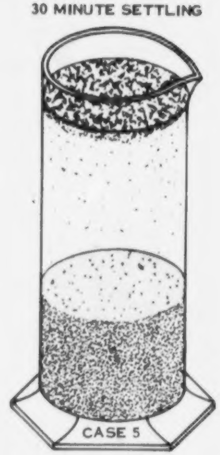
Corrective measures for ashing.

The ashing problem should be approached and solved as follows:

First, stir the sludge which floats in the 30-minute settling test.

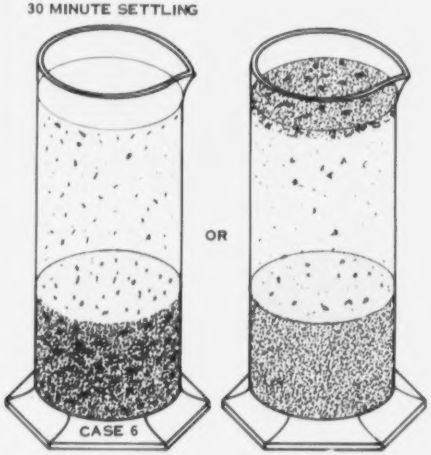
- If it Settles - This indicates that denitrification has begun—See "Sludge Clumping" for solution.
- If it does not settle, there may be excessive amounts of grease in the sludge. Perform a grease analysis. If the grease content exceeds 15 percent by weight of the MLSS, the problem may be one of the following:

- The primary tank scum baffles are malfunctioning due to hydraulic overloading or mechanical failure. Specific attention should be given to scum baffles and the scum collection system in the plant.
- Too much grease is being dumped in the sewer by an industrial or commercial discharger. If too much grease is in the raw wastewater, an industrial waste survey must be conducted to identify the discharger, and have the problem corrected.



OBSERVATION — ACTION — REMEDY

ASH ON SURFACE – STIR FLOATING FLOC
- RELEASES BUBBLES AND SETTLES – BEGINNING OF DENITRIFICATION – INCREASE RETURN OR INCREASE WASTING
- DOES NOT RELEASE BUBBLES NOR SETTLE – PROBABLY EXCESSIVE GREASE CHECK IF GREASE ABOVE 15% OF MLVSS BY WEIGHT
  - TRY TO IMPROVE GREASE CAPTURE UPSTREAM
  - GREASE TRAP CLEANING



OBSERVATION — ACTION — REMEDY

PINPOINT FLOC OR STRAGGLERS OBSERVED IN SUPERNATANT
- DENSE, COMPACT FLOC
  - EXTENDED AERATION ZONE–INCREASE WASTING
  - TO MUCH SHEAR–REDUCE AERATION IF POSSIBLE
- LIGHT, FLUFFY FLOC – F/M TOO HIGH, ORGANIC OVERLOAD – REDUCE WASTING

CASE 5 AND CASE 6

FIGURE II-22

Pinpoint Floc (See Case 6 on Figure II-22)

Old sludge, poor floc.

The appearance of small dense, pinpoint floc particles suspended in the secondary clarifier is a common problem often seen in treatment plants operating near or in the extended aeration range. This problem is generally related to an old sludge that settles rapidly but lacks good flocculation characteristics.

Causes of pinpoint floc.

Some probable causes of the pinpoint floc problem are as follows:

1. The process is being operated at a F/M near or in the extended aeration range resulting in an old sludge with poor floc formation characteristics.
2. Excessive turbulence (overaeration) in the aeration tank shearing the floc formations.

Corrective measures for pinpoint floc.

The following applicable measures should be implemented to correct the problem:

- If the sludge settling characteristics observed during the 30-minute settling test indicate a "too rapidly settling" sludge with poor floc formation, the clarifier effluent quality can be improved by gradually increasing the wasting rate. If nitrification is required, caution must be exercised not to decrease nitrification by wasting too much sludge.
- If good settling with a clear supernatant above the settled sludge is observed in the settling test, check for proper aeration and mixing in the aeration tank. If the average D.O. concentration in the aeration tank is more than 3 mg/l, the SCFM air rate should be reduced until the aeration D.O. is between 1 and 3 mg/l.

Stragglers/Billowing Solids (See Case 6 on Figure II-22)

MLSS too low - young sludge.

The appearance of small, light, fluffy sludge particles rising (sometimes billowing) to the clarifier surface and discharging over the effluent weirs is a problem often seen when the MLSS concentration is too low. This problem is generally related to a young sludge (high F/M) which settles poorly. The problem of light floc particals is generally worse in shallow clarifiers, particularly at high RAS flow rates. At some plants, the flocs are particularly noticeable during the early morning hours.

Causes of stragglers.

Some probable causes of this problem are as follows:

1. The aeration tank is being operated at a MLSS concentration that is too low. This would normally occur during process start-up until the proper MLSS concentration is established. A sludge wasting rate that is too high will result in low MLSS and a high F/M.
2. Sludge is being wasted on a batch basis during the early morning hours resulting in a shortage of microorganisms to handle the daytime organic loading.
3. The return sludge flow rate is high.

Corrective measures for stragglers.

The following applicable measures should be implemented to correct the problem:

- Decrease the sludge wasting rate to raise the MLSS concentration and increase the sludge age.
- If possible, avoid high sludge return rates.
- If wasting sludge on a batch (or intermittent) basis, avoid wasting during the early morning hours. All the organisms are needed at this time to handle the daily increase in organic loading.

REFERENCES

Boe, Owen, K., "Activated Sludge Control With a Settleometer and Centrifuge," U.S. Environmental Protection Agency, Region VIII.

Eckenfelder, W.W., *Biological Waste Treatment*, Pergamon Press, New York, 1961.

Environmental Protection Agency, *Process Design Manual for Upgrading Existing Wastewater Treatment Plants*, 1974.

Hammer, Mark, J., *Water and Waste-Water Technology*, John Wiley & Sons, Inc., New York, 1975.

Hawkes, H.A., *The Ecology of Waste Water Treatment*, Pergamon Press, Oxford, 1963.

Kerri, Kenneth D., et al., "A Field Study Training Program", *Operation of Wastewater Treatment Plants*, (Chapter 7), Sacramento State College Department of Civil Engineering.

McKinney, Ross E., *Microbiology for Sanitary Engineers*, McGraw-Hill Book Company Inc., New York, 1962.

Metcalf & Eddy, Inc., *Wastewater Engineering*, McGraw-Hill, New York, 1972.

Stevens, Thompson, Runyan, Inc., *Operator's Pocket Guide to Activated Sludge*, Parts I and II. Published by the Authors, 5505 S.E. Milwaukie Avenue, Portland, Oregon 97202, 1975.

Stewart, M.J., *Activates Sludge Process Variations - The Complete Spectrum*, Parts I, II, III. Water and Sewage Works, April, May, June, 1964.

Water Pollution Control Federation: "Sewage Treatment Plant Design," *Manual of Practice No. 8*, Washington, D.C., 1967.

Water Pollution Control Federation, "Operation of Wastewater Treatment Plants, *Manual of Practice, No. 11*, 1976.

West, Alfred W., *Operational Control Procedures for the Activated Sludge Process*, Parts I, II, IIIA, and IIIB, U.S. EPA, National Training and Operational Technology Center, Cincinnati, Ohio, 1975.

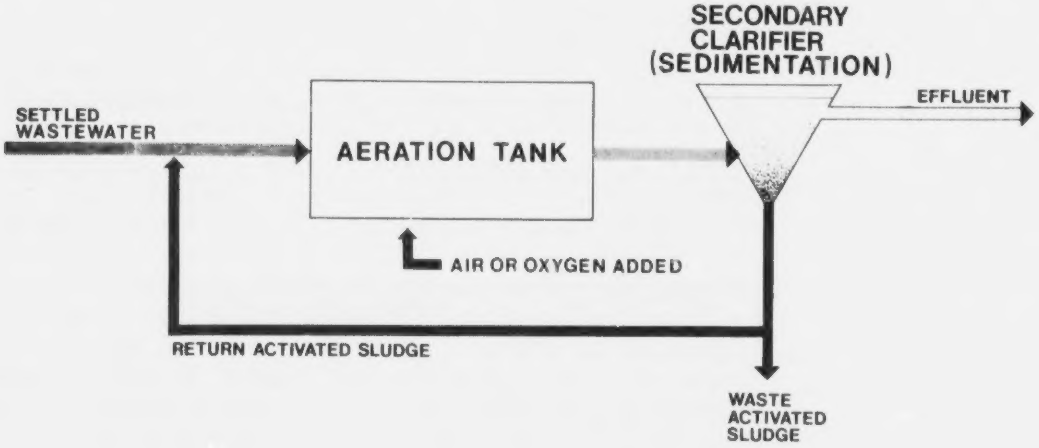
3.01 INTRODUCTION

Where does activated sludge come from?

The term "activated sludge" is derived from wastewater being mixed with air or oxygen for a length of time to develop a brown floc which consists of billions of microorganisms and other material. These microorganisms use most of the suspended and dissolved material found in the wastewater as their food (BOD) source. The microorganisms are aerobic and therefore require an air or oxygen supply to function. Their need for food and air or oxygen is similar to the needs of humans and other animals.

The process provides an environment to control microorganisms.

The activated sludge process provides the environment to keep these microorganisms under controlled conditions so that they can remove most of the solids from the wastewater as it passes through the process. The environment is provided by four basic systems which make up the activated sludge process. These systems include aeration, sedimentation, return activated sludge (RAS) and waste activated sludge (WAS) as illustrated in Figure III-1.



TYPICAL ACTIVATED SLUDGE PROCESS

FIGURE III-1

Process provides treatment to reduce pollution of receiving waters.

The purpose of the activated sludge process is to remove as much of the organic matter in the wastewater as possible by biological means. In doing this, the process produces an effluent quality high enough that beneficial uses of receiving waters will not be hindered; thus, a high level of treatment must be achieved.

Definitions

Be familiar with the terms used in operating the process.

In order for the operator to understand the concepts involved in operating the activated sludge process, he must first understand the terms associated with it.

- ACTIVATED SLUDGE is the floc of microorganisms that form when wastewater is aerated.
- MIXED LIQUOR is the mixture of activated sludge and wastewater in the aeration tank.
- MIXED LIQUOR VOLATILE SUSPENDED MATTER (MLVSS) have been found to be proportional to the microorganisms concentration in the aeration tank.
- KINETICS is the approach used to mathematically simulate biological treatment processes by relating the growth rate of the microorganisms to the food and microorganism concentration.
- NET GROWTH RATE is the microorganism rate of growth minus the microorganism decay rate. Also referred to as the net sludge yield.
- MEAN CELL RESIDENCE TIME (MCRT) is the inverse of the net growth rate and is equal to the average time a microorganism spends in the treatment process. The MCRT is an important kinetic parameter that is very useful in process control.
- FOOD TO MICROORGANISM RATIO (F/M) is the ratio of the amount of food expressed as pounds of COD (or BOD) applied per day, to the amount of microorganisms, expressed as the solids inventory in pounds of volatile suspended matter. The F/M is mathematically related to the MCRT, and is also an important process control tool.
- GOULD SLUDGE AGE (GSA) is the ratio of the pounds per day of influent wastewater suspended matter to the solids inventory in the aeration tank. Thus, GSA or Sludge Age should not be confused with the term MCRT.
- RETURN ACTIVATED SLUDGE (RAS) is the settled mixed liquor that is collected in the clarifier underflow and returned to the aeration basin.
- WASTE ACTIVATED SLUDGE (WAS) is the excess growth of microorganisms which must be removed to keep the biological system in balance. Various control techniques have been developed to estimate the amount of WAS that must be removed from the process.
- COMPLETE MIX ACTIVATED SLUDGE describes an ideal mixing situation where the contents of the aeration tank are at a uniform concentration. In other words, everything in the tank is dispersed by a back mixing action.
- PLUG FLOW ACTIVATED SLUDGE describes an ideal situation where the contents of the aeration tank flows along the length of the tank.
- BACK MIXING refers to mixing the contents of a tank in the longitudinal or flow oriented direction.
- TRANSVERSE MIXING, also known as cross roll, refers to mixing in a direction across the direction of flow.
- SLUDGE REAERATION refers to the practice of aerating the RAS before it is added to the mixed liquor.
- PROCESS LOADING refers to the organic loading range as measured by the F/M.
- CONVENTIONAL LOADING refers to a process loading of 0.2 to 0.5 lbs BOD applied/lb MLVSS/day.
- HIGH RATE LOADING refers to a process loading of two to three times the conventional loading rate.

- EXTENDED AERATION LOADING refers to low rate loading that is one half to one tenth of the conventional loading rate.
- SETTLEABILITY is the measure of the volume occupied by the mixed liquor after settling in a graduated cylinder for 30 minutes. Settleability is generally expressed as a percentage based on the ratio of the sludge volume to the supernatant volume.
- SOLIDS INVENTORY is the amount of volatile suspended solids in the treatment system. The Solids Inventory is also known as the Volatile Solids Inventory.

3.02 PROCESS DESCRIPTION

Influent Wastewater combined with RAS to form Mixed Liquor.

The activated sludge process involves growing microorganisms on the organic material in wastewaters. Return Activated Sludge (RAS) from the clarifier underflow is combined with the influent wastewater in the aeration tank to form the mixed liquor. The mixed liquor is usually aerated for a period of several hours in the aeration tank. During this time some of the organic material in the wastewater is converted into new microorganisms and some in converted (oxidized) to various other products including carbon dioxide. The mixed liquor flows through the aeration tank and into the clarifier where it settles to form the RAS. The clear liquid remaining above the settled mixed liquor is called the secondary effluent which is discharged from the process.

Waste Activated Sludge.

Process Balance based on food limited growth

A portion of the activated sludge is purposely removed by wasting it from the process. The wasting of sludge is necessary to maintain the desired quantity of microorganisms in the process. Wasting is necessary because the microorganisms grow and multiply as they eat the food supply in the wastewater. The basic idea behind successful operation of an activated sludge system is to keep a balance of microorganisms to the amount of food in the wastewater. Proper operation will provide the microorganisms with a balanced diet of food, nutrients, and oxygen. If nutrients or oxygen limit the growth of the microorganisms, they will not settle satisfactorily in the clarifier. Proper operation makes food the only part of microorganisms diet that limits their growth. As long as food is the only limit to their growth, the process can be controlled and maintained so that they settle well in the clarifier.

Well settling mixed liquor is the key to activated sludge treatment.

If the organic material conversion process is limited by oxygen or nutrients, the microorganisms in the mixed liquor will not settle well in the secondary clarifier. The activated sludge process depends on settling the mixed liquor so that it can be returned to the aeration tank to keep in balance with the organic material in the incoming wastewater. This balance is generally related to process loading as expressed by the F/M ratio. Inability to settle the mixed liquor can result in a high concentration of suspended solids in the clarifier effluent. Proper control of the activated sludge process will produce a mixed liquor with good settleability. If the conditions in the aeration system deteriorate, the formation of undesirable microorganisms can result. Typical undesirable microorganisms include the filamentous organisms. Filamentous microorganisms grow as long, thread-like organisms having an increased surface area. This increased surface area makes it possible for the filamentous organisms to grow in conditions of low dissolved oxygen or low nutrient

Filaments make poor settling sludge.

concentrations. Unfortunately, filamentous organisms hinder settling by causing excessive bridging and matting of the flocs, resulting in a mixed liquor which does not settle well. Poor settleability associated with the presence of too many filamentous organisms is known as bulking sludge.

Cure bulking by making environment less suitable for their growth.

The consequences of bulking sludge are that poorly settling mixed liquor cannot be returned to the aeration tank and that the clarifier effluent suspended solids will be high. Operation in a bulking sludge condition will eventually result in the loss of the mixed liquor over the weirs into the effluent. Typical approaches to curing bulking include treating the return activated sludge with oxidizing agents, such as chlorine or hydrogen perioxide, and improving treatment conditions so that the environment is less favorable to the growth of filamentous organisms.

Aeration System

Aeration provides DO and mixing.

Aeration serves the dual purpose of providing dissolved oxygen and mixing of the mixed liquor and wastewater in the aeration tank. Aeration is usually provided by either diffused air or mechanical aeration systems. Diffused air systems consists of a blower and a pipe distribution system that is used to bubble air into the mixed liquor. Mechanical aeration systems consist of a pumping mechanism that disperses water droplets through the atmosphere.

Diffused Air System

Most common.

Diffused air systems are the most common types of aeration systems used in activated sludge plants. The distribution system consists of numerous diffusers generally located near the bottom of the aeration tank. The diffusers are located in this position to maximize the contact time of the air bubbles with the mixed liquor.

Fine and coarse bubbles.

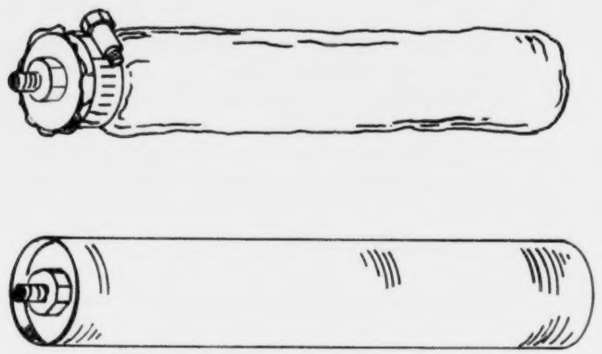
Diffusers are designed to either produce fine or coarse bubbles. Fine bubble diffusers were used frequently in the treatment plants designed in the period from 1950 to 1970, because it was felt that the increased oxygen transfer efficiency* of the fine bubble diffusers was important. Unfortunately, the fine bubble diffusers are easily clogged by biological growths and by dirty air, resulting in high maintenance costs.

Fine Bubble Diffusers

The most common type of fine bubble diffusers are nylon or dacron socks and saran wrapped tubes. These diffusers have oxygen transfer efficiencies of around eight percent. Sketches of these types of fine bubble diffusers are shown below in Figure III-2.

Tend to clog.

The major limitation of fine bubble diffusers is that they are easily clogged. Diffusers are self-sealing if dirty air is pumped into them. The diffusers are also subject to clogging because of biological growths. The air supply for all fine bubble diffusers should be filtered. Refer to Section I, "TROUBLESHOOTING", for observations which indicate diffuser clogging.



SKETCHES OF A NYLON SOCK,
AND A SARAN WRAPPED TUBE

FIGURE III-2

*Oxygen transfer efficiency is defined as the amount of oxygen transferred to the water divided by the amount of oxygen supplied.

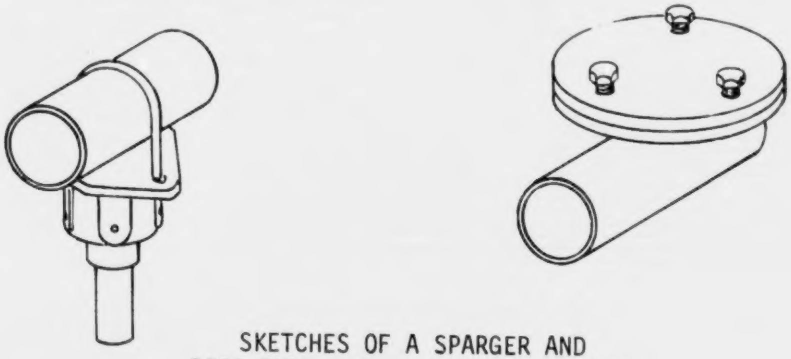
Coarse Bubble Diffusers

Lower oxygen transfer efficiencies, lower costs and maintenance requirements.

Coarse bubble diffusers are usually made by drilling holes in pipes or by loosely attaching plates or discs to a supporting piece of pipe. Coarse bubble diffusers have lower oxygen transfer efficiencies than the fine bubble diffusers. A typical oxygen transfer efficiency would be about 5 percent. Coarse bubble diffusers are becoming increasingly popular because of their lower costs and maintenance requirements.

Substantially less maintenance needs.

Many of the treatment plants surveyed during the on-site visits had changed over to the coarse bubble diffusers, and these plants reported that the coarse bubble diffusers were working quite well. The maintenance needs were reported to be substantially less than those of the fine bubble diffusers. Figure III-3 presents sketches of two types of coarse bubble diffusers.



SKETCHES OF A SPARGER AND
DISC TYPE COARSE BUBBLE DIFFUSER

FIGURE III-3

Mechanical Aeration Systems

Surface and Turbine.

There are two types of aerators in common use today. These include the surface and turbine aerators. Surface aerators use a rotating propeller that pumps the mixed liquor through the atmosphere above the aeration tank. Oxygen transfer is achieved by the aerator propeller spraying the mixed liquor through the atmosphere. Turbine aerators increase oxygen transfer efficiency by creating turbulence in the area of the rising bubbles.

Surface Aerators

Floating or platform mounted.

Surface aerators either float or are mounted on supports in the aeration tank. Materials, such as epoxy coated steel are used in the construction of surface aerators to reduce corrosion.

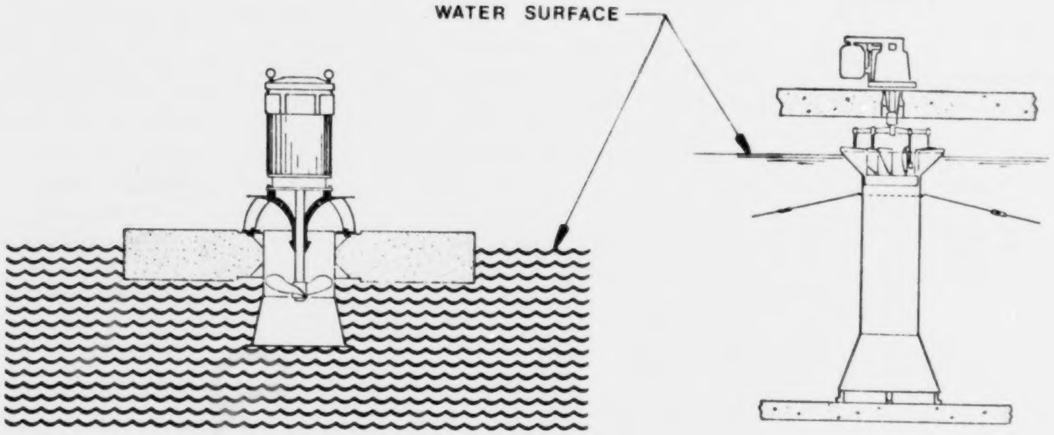
The oxygen transfer efficiency of a surface aerator increases as the submergence of the propeller is increased. However, power costs also increase because more water is sprayed.

Oxygen transfer 2 lb O_2/hp/hr.

Oxygen transfer efficiencies for surface aerators are stated in terms of pounds of oxygen transferred per horsepower per hour (lb O_2/hp/hr). Typical oxygen transfer efficiencies are about 2 lb O_2/hp-hr. Surface aerators are sometimes equipped with draft tubes to improve their mixing characteristics.

Another type of surface aerator used in oxidation ditches is the brush aerator, which is a horizontally mounted brush located just below the water surface. The brush is rotated rapidly in the water to supply mixing and aeration.

Figure III-4 shows a floating and a platform surface aerator.



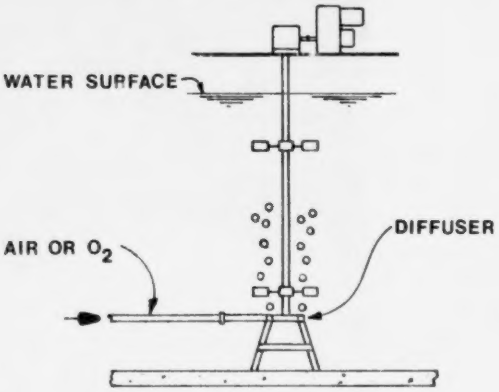
TYPICAL FLOATING AND PLATFORM SURFACE AERATORS

FIGURE III-4

Improved oxygen transfer—Use in complete mix process.

Turbine Aerators

Turbine aerators are used because of improved oxygen transfer efficiency and lower horsepower requirements. Turbine aerators are most frequently used in complete mix activated sludge processes. Figure III-5 shows a typical turbine aerator without the draft tube.



TYPICAL TURBINE AERATOR

FIGURE III-5

Sedimentation System

Function of secondary clarifier.

As the mixed liquor flows out of the aeration tank, it is transferred to a sedimentation unit which is commonly called a secondary clarifier. The secondary clarifier provides a reduction in flow velocity needed to allow the mixed liquor to separate from the treated wastewater and settle by gravity to the bottom. Effective settling depends on maintaining the best balance between the microorganisms in the mixed liquor and the organic material contained in the wastewater to be treated. A good quality activated sludge is essential to achieve good settling characteristics. A process control parameter which relates to this balance is called the F/M ratio.

Description.

The design and construction of secondary clarifiers for activated sludge treatment incorporates several methods for the removal of settled sludge. These generally include the conventional sludge collection equipment found in rectangular and circular primary sedimentation units which collects to a central hopper and, in recent years, suction-type collectors as shown in Figure III-6. Determination and review of clarifier operational parameters are discussed in Section 2.03, "PERFORMANCE EVALUATION."

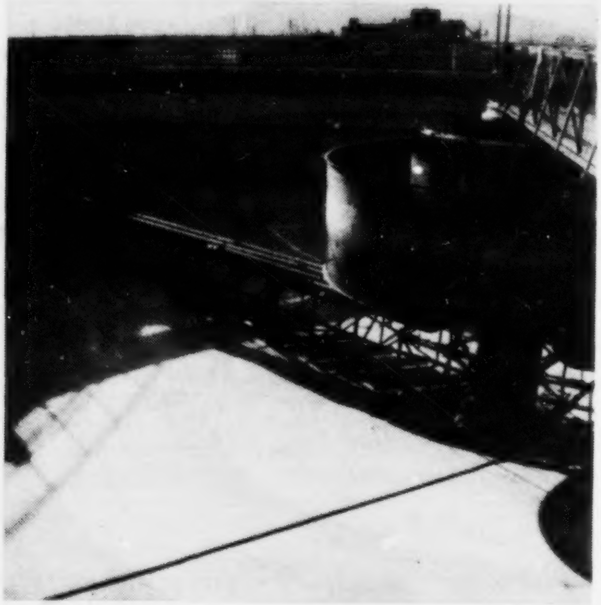


Figure III-6
Sludge Collector with Suction Draw Tubes

3.03 ACTIVATED SLUDGE PROCESS VARIATIONS

Most technical articles have been written for the engineer and not the operator.

In the past many technical articles have been written, describing a number of different variations of the activated sludge process. Generally the processes included are conventional, tapered aeration, complete mix, extended aeration, step aeration, contact stabilization, and the Kraus process. Unfortunately, these discussions have been rather simplified and they have not kept pace with our increasing understanding of the principles behind all the activated sludge processes. The articles have been written with the design engineer rather than the operator in mind. A related problem is the fact that most articles discussing the application of process theory to operation do not describe the operation of these individual process variations, but, rather, describe principles that are supposed to apply to the process in general, or to the complete mix or conventional process modes. Another problem is that some of the "process variations" are very difficult, such as the conventional and contact stabilization processes, and others are very minor variations or more basic processes, such as tapered aeration.

Only two basic ways of evaluation process variations
1) Loading
2) Physical arrangement.

If one studies the problem, it becomes obvious that there are only two basic ways of looking at the question of activated sludge process variations: from the standpoint of the various ranges of process loading, and from the standpoint of the various physical arrangements of the process. The various levels of process loading are described by the F/M ratio and MCRT. The term, "physical arrangements" is used to refer to the structural arrangement of the aeration tank as well as the various arrangements of the process streams that are used to provide flexibility.

Process Loading Ranges

Three basic loading ranges.

Over the years a number of studies have been conducted describing the influence of process loading on the behavior of the activated sludge process, and most of these have identified three basic ranges of process loading where the aeration solids can be successfully settled making process operation feasible. The three basic ranges of process loading are shown in Figure III-7 for a plant operating on a typical domestic wastewater at a temperature of about 20 degrees centigrade. For the purpose of this discussion, these loading ranges will be referred to as the high rate, coventional rate, and extended aeration.

The loading range is often fixed by design.

Generally the range of process loading in which a plant is to be operated is not a matter for the operator to decide. In fact operators who try to operate a plant in a loading range other than that for which it was designed are usually disappointed, and this practice is not recommended. Most plants of 1 mgd or more are designed to operate in the conventional range, although many are designed to operate in the lower portions of that range to ensure that effective nitrification occurs.

High Rate

Not commonly used.

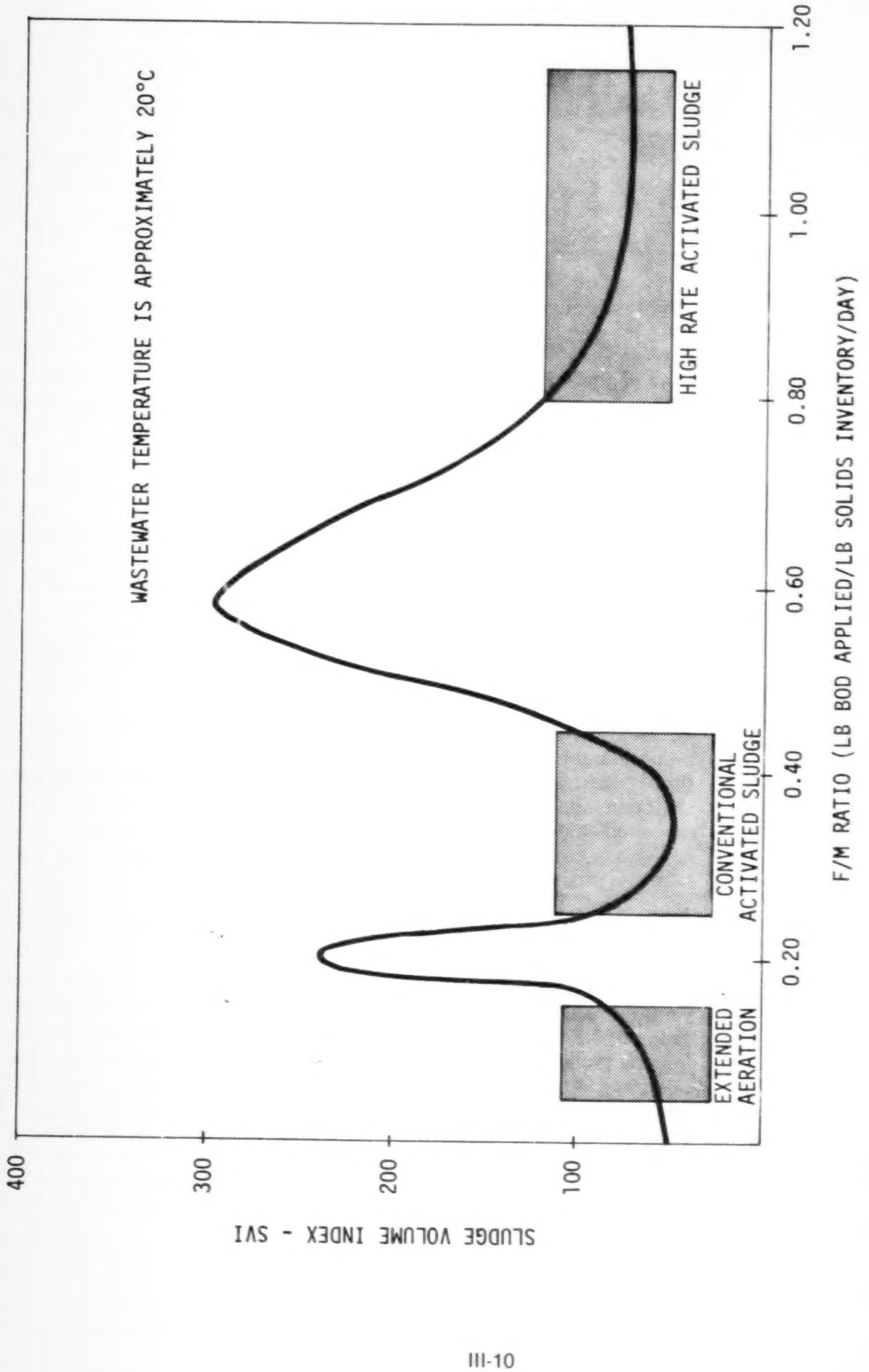
The high rate loading range takes advantage of the settleability of sludge when the treatment system is loaded at a fairly high rate. Generally, the level of treatment which results is somewhat comparable to a typical high-rate trickling filter plant. Although the process can be applied effectively in certain situations, large-scale use of this modification of the process at their 300 mgd Hyperion plant, choosing to treat only about one better than it is at slightly lower loadings, is apparently not good enough and this, combined with the higher level of soluble BOD, greatly reduces the treatment efficiency. The City of Los Angeles has abandoned this process at their 300 mdg Hyperion plant, choosing to treat only about one third of their flow at conventional loading levels. Apparently the quality of the combined effluents consisting of 100 mgd treated by conventional activated sludge and 200 mgd treated with primary sedimentation only is as good or better than the quality when the entire flow was treated by the high rate process.

Conventional Rate

Typical operation for medium and large sized plants.

Nitrification at lower end of loading range.

For a typical domestic wastewater at about 20 degrees centigrade the conventional process operates between MCRT values of 5 to 15 days and F/M ratios of 0.2 to 0.5 lbs BOD applied/lb MLVSS/day. Most large municipal treatment plants operate in the conventional activated sludge zone. Plants operating in the middle of this range produce an excellent effluent quality and do not nitrify. At the lower end of this loading range, an even better effluent is sometimes produced although problems sometimes occur when the plant slips slightly or goes completely into nitrification, which often results in operational problems such as rising sludge in the clarifiers, the appearance of filaments in the sludge, and the formation of a brown, greasy-appearing foam.



SLUDGE SETTLEABILITY VS. ORGANIC LOADING

FIGURE III-7

Poor sludge settleability at upper end of loading range.

Filamenteous growths and poor sludge settleability have been associated with the conventional process at the upper end of this loading range. Dispersed growth and a cloudy effluent are also quite common. Usually the operator can see this sort of condition coming by plotting a trend of the organic loading in his treatment process (either the F/M ratio or the actual MCRT). Other signs of a more physical nature may also be used by the operator to evaluate an "overloaded" condition. For example, once high loading levels are reached, a stiff, white detergent-type foam is often observed on the aeration tanks.

Extended Aeration Rate

Frequently used with smaller plants—Less WAS than conventional plant.

Occasional wasting is essential.

The lowest range of process loading where successful operation may be accomplished is the extended aeration range. Generally plants operating in this range are small in size and do not receive 24 hour supervision. Such plants are very conservative in design and generally operate with an MCRT of 20-40 days and F/M ratio of 0.05 to 0.15 lbs BOD applied/lb MLVSS/day, based on typical domestic wastewater at a temperature of 20° C. The extended aeration process is sometimes referred to as the "total oxidation process". This name is derived from the fact that these plants are designed with such low loadings that the simple kinetics theory used to describe processes of higher loading would predict that all of the influent BOD will be converted to CO_2. This is why some manufacturers claim that no wasting is necessary for their extended aeration designs. In actual fact, there is no such thing as the "Total Oxidation Process" and even after extremely long periods of aeration, suspended matter remain in the effluent. Although sludge wasting need not be conducted on a daily basis in plants operating in the extended aeration range, occasional wasting is an absolute necessity.

Pin floc is frequent problem.

Denitrification is also a problem

Often the effluent of the extended aeration processes contains small pinpoint floc which may be observed passing over the weirs of the secondary clarifier. When the loading in an extended aeration plant is in the higher portion of the loading range, a number of operating problems may occur. Because the entire extended aeration range is in the nitrification zone, denitrification and rising sludge problems may result. Also the same brown, greasy foam, filaments, and poor settleability mentioned in discussion of the conventional process at low loading may occur under these circumstances. If possible, these problems may be improved by using additional aeration capacity or decreasing the level of MLSS.

Wasting is necessary.

Other problems associated with the extended aeration process have to do with the fact that some sludge must be wasted and that many operators have been told that wasting is not necessary, indeed, many small extended aeration plants have no facilities installed to make wasting possible. Under these circumstances, it is not uncommon for sludge to creep over the clarifier weirs whenever fluctuations in flow occur. Unfortunately, this results in a significant reduction in removal efficiency.

Control sludge wasting.

If the operator of an extended aertion plant frequently experiences losses of solids over the effluent weirs, there are two remedies which can be used; regular sludge wasting, and flow equalization. Of the two, sludge wasting is by far the most important. A conscientious operator should keep track of the solids he intentionally wastes, and the solids that go over the effluent weirs. In this manner, the plant can be operated to achieve a specific value of MCRT.

Need to have wasting facilities.

If plant design provisions have not been made for sludge wasting, the operator should attempt to improvise some sort of temporary or permanent method. Depending on the specific design of the plant and the geography and environmental conditions around it, the operator may be able to arrange for constructing sludge beds or lagoons for wasting facilities. The sludge from plants of this sort is generally already "aerobically" digested: and therefore, if it is placed directly on a sand bed for drying, or in a lagoon, it will generally not have a foul odor.

Extended aeration plants subject to problems due to flow variation.

Even when regular wasting is carried out, a high degree of flow variation in extended aeration plants will often cause solids losses. This is probably due to the particular characteristics of the floc produced in the low loading range as well as to the flow variations themselves. In some cases, if the aeration tank is large enough, the operator can design a makeshift system which will allow the use of the aeration tank as a flow equalization device. Minor modifications of this sort will go a long way to improve suspended solids removal in plants where losses are primarily due to hydraulic fluctuations.

Physical Arrangements of the Process

Physical layout of process.

As mentioned previously, the term "physical arrangements" is used in this discussion to describe the structural arrangement of the aeration tank as well as to the various arrangements of process streams that are used to provide process flexibility. Using this sort of description there are only three physical arrangements which are presently used to any great degree in modern activated sludge plants in the United States. These are complete-mix activated sludge, plug-flow activated sludge, and activated sludge with reaeration.

Complete Mix Activated Sludge

Contents of tank uniformly mixed.

Measure DO or SS to check uniformity of mixing.

Dye studies too!

In an ideal complete-mix activated sludge plant, the contents of the tank are completely homogeneous. In order to ensure that this is achieved, special arrangements are often employed to uniformly distribute the influent and withdraw the effluent from the aeration tank. Attention to the tank shape and to intensive mixing is important. There are a number of means which the operator may use to evaluate the degree to which his particular process operates in the complete mix mode. First and foremost the entire contents of the tank should be completely uniform. This can be confirmed by measurements of dissolved oxygen and suspended solids. If the tank is thoroughly mixed, these measurements should be nearly uniform. Dye studies may also be used and will provide even more accurate information; however, conducting these studies is usually beyond the capability of a typical treatment plant.

Typical laboratory model

The complete mix process is important because it operates well, but also because most laboratory and pilot scale studies use this process arrangement.

Best understood.

For this reason, the complete-mix process is probably the best understood of the three basic process arrangements that will be discussed here. In fact most of the information developed by the research community can be applied to the complete-mix process with much less reservation than it can to other processes.

Very stable because shock loads are diluted.

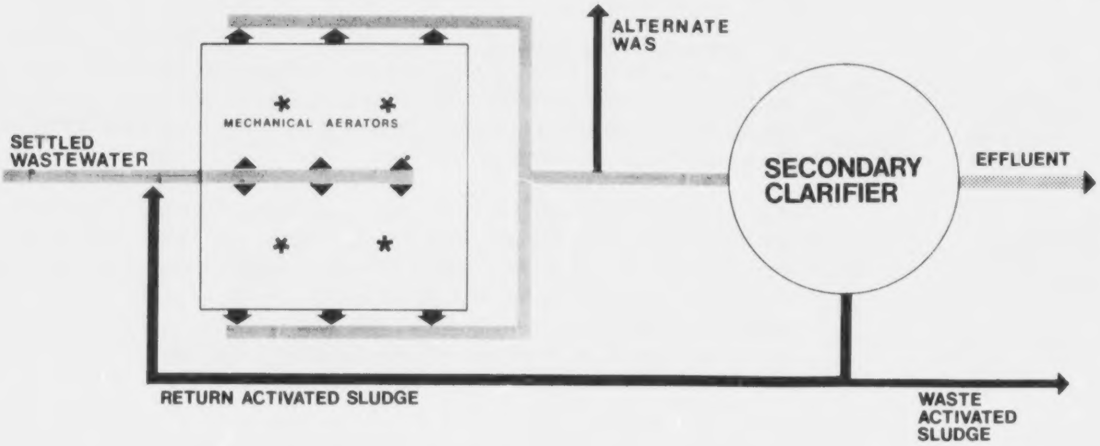
As a general rule, the complete-mix process is a very stable process which is resistant to upsets from shock loads of all kinds. This is a direct result of the fact the shock is almost uniformly spread throughout the entire aeration chamber. Some of the stability of this process may also be due to the fact that the same environment prevails throughout the entire tank. As a result, a relatively uniform population of microorganisms are developed in an environment which is nearly the same throughout.

No unique operating problems.

Evidence to date does not show any special operating problems which are unique to the complete-mix process, however, there are a few comments that can be made about the process in general. Some people express concern about the fact that some of the wastewater may be immediately transported from the influent to the effluent end of the aeration tank without receiving much treatment. A strict application of the principles of chemical engineering to such a physical arrangement would indeed suggest that it may be less efficient than others. However, the data available at present on the relative performance of the complete-mix process show that it is just as efficient as other process arrangements. It would appear that the application of a rather simplified chemical engineering view of the complete-mix theory overlooks other facts which are of overriding importance.

The other major area of comment with regard to the complete-mix process has to do with sludge settleability. There is considerable evidence accumulating to the effect that the complete-mix process may operate with a higher typical level of SVI or lower settleability than do competitive process arrangements. Insufficient evidence is available at the present time to prove or discount this contention, however, it should be recognized that the settleability of complete-mix sludges is generally well within the range of normal operation and the competitive process arrangements which develop floc having lower SVI's during operating conditions also have more inconsistent operation.

A schematic of a typical complete-mix activated sludge process is presented on Figure III-8.



COMPLETE MIX ACTIVATED SLUDGE

FIGURE III-8

Plug-Flow Activated Sludge

Wastewater and RAS flow through the plant as a slug or plug.

In an ideal plug-flow plant, both the untreated wastewater and the return sludge are introduced at the head end of the aeration tank and the mixed liquor is withdrawn at the opposite end. A pulse of dye added at one end the tank would emerge at the other end exactly as it had entered after a delay equal to the hydraulic detention time. Ideally the flow passes through the aeration tank as a "plug" without much longitudinal mixing (mixing in the direction of flow). Because the tank must be aerated, however, longitudinal mixing cannot be avoided. Generally, long serpentine patterns of flow and aeration in a spiral pattern are used to encourage plug-flow characteristics. The best means for approaching plug-flow characteristics in an aeration tank, however, is to compartmentalize the chamber into a series of completely mixed reactors. A series of 3 or more compartments will do as good a job as some of the best "plug-flow" designs of the traditional sort, and a greater degree of compartmentalization will provide flow characteristics even closer yet to the plug flow ideal. Many plants of conventional design can be modified to improve their plug-flow characteristics by the use of lighweight partitions to compartmentalize the aeration tanks.

Adding lightweight partitions is a possible modification to improve performance.

Process is more susceptible to shock loads.

The plug flow process is more susceptible to adverse effects from shock loads than the other processes. This is because the shocks are applied to the microorganisms at the head end of the tank at maximum concentration. Adequate dissolved oxygen levels are difficult to maintain at the head end of the process because such a large oxygen demand is exerted in one location. The tapered aeration process is an effort to deal with this problem.

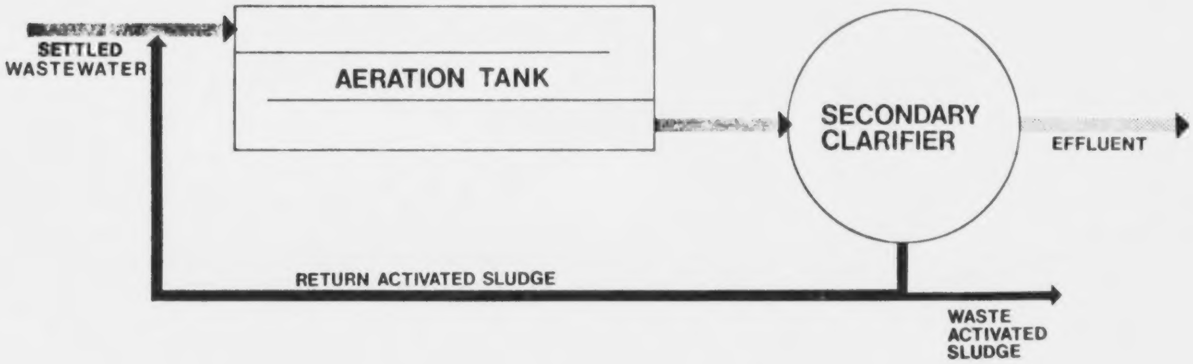
Tapered Aeration.

Tapered aeration is designed to solve this problem by adding greater amounts of air at the head end of the tank where most of the demand is exerted. In one form or another, tapered aeration is used in most modern plug-flow activated sludge plants and it should not be considered as a completely independent process option.

Plug Flow is very popular and can produce high quality effluent.

Despite the shortcomings resulting from shock loads and difficulties encountered in maintaining adequate dissolved oxygen, the plug-flow process remains very popular and some of these plants are consistently producing some of the best effluent. Studies have shown that the varied conditions which the sludge is exposed to as it passes through the aeration tank produces a healthy and good settling sludge. Plug-flow activated sludge plants are very effective where the wastewater is mostly domestic and good industrial waste control is practiced.

A schematic of a typical plug flow activated sludge process is presented on Figure III-9.



PLUG FLOW ACTIVATED SLUDGE

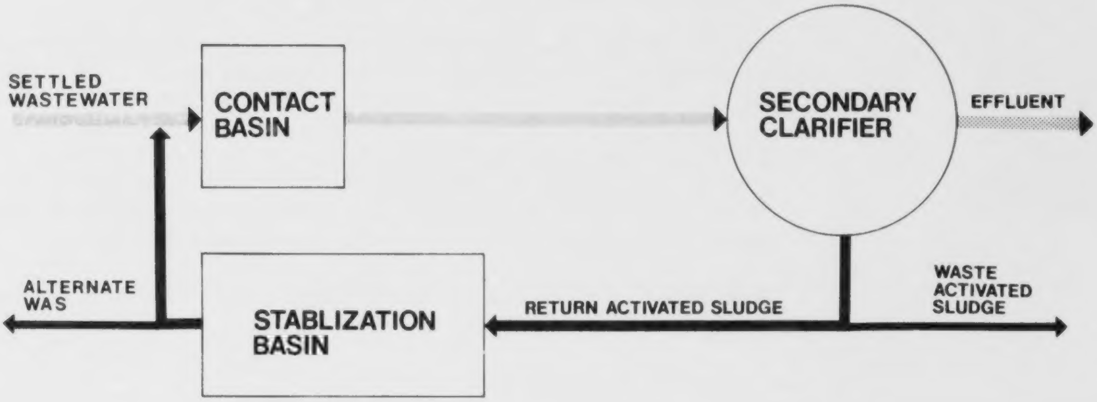
FIGURE III-9

Activated Sludge with Sludge Reaeration

Reaeration is a variation of arrangement of the process streams.

Contact Stabilization Step Aeration.

Whereas plug-flow and complete-mix are essentially variations in aeration tank design and mixing, the sludge reaeration processes are variations in the arrangement of the process streams. All sludge reaeration processes involve stabilization by aeration of the return sludge prior to its contact with the untreated wastewater. Most examples require different ratios between the amount of return sludge under aeration and the amount of sludge in the contact section of the process. Contact stabilization (Figure III-10) and step aeration (step feed) (Figure III-11) are two of the most popular variations of sludge reaertion. In their typical arrangement, these two processes represent the extremes of the contact/stabilization ratio, however, both of them have established a successful record of performance. In fact, successful process installations with contact/stabilization ratios over the whole range between contact stabilization and step feed can be found in great numbers. Most of these processes have definitely been shown to greatly increase the capacity of the activated sludge process to handle high organic loadings in smaller aeration tank volumes and some have argued that they are also more resistant to shock loading.



CONTACT STABILIZATION ACTIVATED SLUDGE

FIGURE III-10

Sludge Reaeration is less well understood than other variations.

The various arrangements of sludge reaeration have been studied much less on a laboratory and pilot scale basis than have the other basic process arrangements, complete-mix and plug-flow. Of the three basic process arrangements discussed here, the sludge reaeration processes are the least well understood. On the other hand, they are processes which have demonstrated great potential.

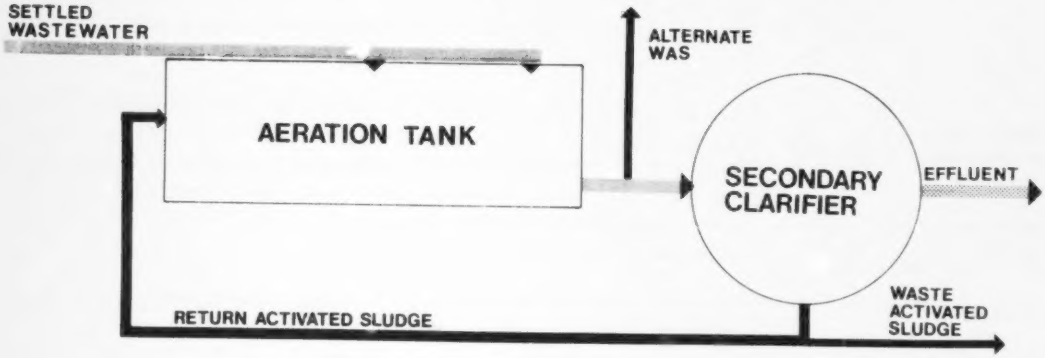
However, a certain amount of information is available on the behavior of the sludge reaeration processes based on field and pilot scale data. This data will be used to describe the processes and their behavior to the extent possible.

Includes solids in the Contact and Stabilization basins in the F/M calculations.

First of all, although volumetric loadings for the sludge reaeration processes may be considerably higher than for the two processes described previously, the overall F/M ratios or MCRT values which may be used for operation are in about the same range, i.e., in the range which has been described as conventional activated sludge (F/M values of 0.2 to 0.5 and MCRT values of 5 to 15 days). In doing these calculations all the solids in the process should be included in the solids inventory and F/M calculations.

COD removal not significantly affected by the volume ratio of Contact to Stabilization basin.

Although it has been adequately demonstrated that the ratio of solids in the contact section and in the reaeration section has a significant impact on the degree of removal of certain compounds such as ammonia, the removal of organic material (COD or BOD) from domestic effluents does not seem to be significantly affected over a very broad range of contact/stabilization ratios. For this reason, the effluent quality seems to be about



STEP FEED ACTIVATED SLUDGE

FIGURE III-11

the same in processes ranging from step aeration, where the reaeration section is usually quite small to the contact section. All organic wastes are not of exactly the same nature. If removals of organic materials are not as high as expected, the operator should consider taking measures to increase the fraction of the sludge inventory which resides in the contact section. The most simple means of accomplishing this is to increase the recycle ratio. If this measure has been used to the limit of its value, other options are frequently available. Among the most important of these are the distribution of raw wastewater feed in a step aeration design and the addition of another tank to the contact section in others.

Important point to be considered.

Most of the benefits of sludge reaeration are achieved if the organic load present is mainly in the colloidal state. Generally, the greater the fraction of soluble BOD, the greater the required contact time. As a result, the required total aeration volume of this process approaches that of the conventioanl process as the relative amount of soluble BOD in the wastewater increases.

Control of sludge return more important than in other variations

The control of sludge return assumes much greater importance in the sludge reaeration processes than it does in the other activated sludge variations. For example, the rate of return (or the recycle ratio) affects not only the solids balance between the contact and stabilization sections, but it is also very important for controlling the overall solids inventory and the concentration of solids in the contact section.

Do not control RAS with just the blanket level in the clarifier.

If the rate of return is controlled in reaeration processes in the same manner as was suggested for complete-mix and plug-flow some problems would result. For example, if the return were operated according to the level of the sludge blanket in the secondary clarifier, the reaeration bays would always be full of sludge which would be at the maximum concentration that could be achieved in the clarifier. Chances are this concentration does not correspond to the proper F/M ratio for operation. If the recycle ratio is increased beyond this level, some water will be mixed in with the solids and the concentration in the reaeration bays would be reduced. Thus, it is possible to adjust the ratio of the solids in the contact and reaeration bays through the use of the rate-of-return.

RAS is used to control solids ratio in the Contact and Stabilization basins.

This same phenomenon is also important in controlling solids wasting in a sludge reaeration plant. For example, if the return rate is set up so that the maximum concentration of return is always provided when wasting is attempted, the result will always be to reduce the concentration of sludge in the contact section without substantially influencing the concentration in the reaeration section.

WAS must be carefully controlled.

Inexpensive conversion to Contact Stabilization.

In general, the sludge reaeration processes are a very good means of improving the capacity of a given set of aeration tanks to handle a higher BOD load. Operators having overloaded plug-flow or complete-mix plants, should consider alterations to accommodate some sludge reaeration if possible. Many times this conversion can be accomplished with only a small investment in additional piping. One of the big advantages of the reaeration processes is they reduce the solids loading on the final clarifiers.

REFERENCES

Eckenfelder, W.W., *Biological Waste Treatment*, Pergamon Press, New York, 1961.

Environmental Protection Agency, *Process Design Manual for Upgrading Existing Wastewater Treatment Plants*, 1974.

Hammer, Mark J., *Water and Waste-Water Technology*, John Wiley & Sons, Inc., New York, 1975.

Hawkes, H.A., *The Ecology of Waste Water Treatment*, Pergamon Press, Oxford, 1963.

Kerri, Kenneth, D., et al., *A Field Study Training Program, Operation of Wastewater Treatment Plants*, (Chapter 7), Sacramento State College Department of Civil Engineering.

McKinney, Ross E., *Microbiology for Sanitary Engineers*, McGraw-Hill Book Company Inc., New York, 1962.

Metcalf & Eddy, Inc., *Wastewater Engineering*, McGraw-Hill, New York, 1972.

Stevens, Thompson, Runyan, Inc., *Operator's Pocket Guide to Activated Sludge*, Parts I and II. Published by the Authors, 5505 S.E. Milwaukie Avenue, Portland, Oregon 97202, 1975.

Stewark, M.J., *"Activated Sludge Process Variations - The Complete Spectrum,"* Parts I, II, III, Water and Sewage Works, April, May, June, 1964.

Water Pollution Control Federation: *"Sewage Treatment Plant Design,"* Manual of Practice No. 8, Washington, D.C., 1967.

4.01 INTRODUCTION

Laboratory control is an essential tool.

An essential tool for proper process control is frequent and accurate sampling an laboratory control tests. By relating the lab test results to operation, the operator can select the most effective operational parameters, determine the efficiency of his treatment processes, and identify developing problems before they seriously affect effluent quality. Therefore, laboratory facilities play an important role in the control of an aerobic biological treatment facility.

4.02 LABORATORY SAMPLING AND TESTING PROGRAM

Good sampling technique is essential.

Good sampling procedures are the key to meaningful laboratory analyses. A typical sample represents only a small fraction of the total flow, and great care must be exercised to ensure that the sample is representative. If this is not accomplished, the subsequent analytical data is worthless for process control. Therefore, the importance of good and accurate sampling techniques cannot be overstressed.

The exact location of sampling points within a given treatment plant cannot be specified because of the varying conditions and the plant design. However, it is possible to present certain general guidelines which are presented on Figure IV-1.

Two types of samples.

Two types of samples may be collected, depending upon the purpose of sampling. The first is a dip or "grab" sampling which consists of a single portion collected at a given time. The second type of sample is a "composite" sample that consists of portions taken at known times and then combined in volumes that are proportional to the flow at the time of sampling. These combined portions produce a sample which is representative of the wastewater characteristics over the entire sampling period.

24-hour composite sampling is preferred.

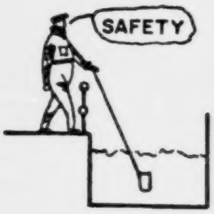
The preferred sampling procedure, except for certain lab tests which must be run immediately (Dissolved Oxygen, Temperature, pH), is to collect hourly samples for 24 hours with the volume of sample in proportion to the wastewater flow rate. When available and where possible, automatic sampling devices should be employed. The sample containers and sample lines should be frequently cleaned to prevent sample contamination. The hourly grab samples should be composited into a labeled plastic gallon bottle and kept refrigerated at 3 or 4° C. to prevent bacterial decomposition. For some tests (such as the nitrogen tests), other methods of preservation may be needed, refer to Standard Methods for recommended preservation procedures. A final composited sample volume of 2 to 3 liters is usually sufficient for conducting routine tests. Where collection of an hourly sample is not feasible, a 2 or 3 hourly sampling procedure is the next best alternative. The sampling method and time of sampling should be noted upon the lab record (log) sheet as reference for later data review and interpretation.

If only grab samples are collected, the operator must sample during peak flow conditions.

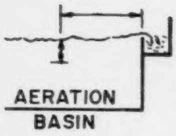
Grab Samples

Grab samples are representative of the instantaneous characteristics of the wastewater. If it is only possible to collect grab samples, they should be collected when the treatment plant is operating at peak flow conditions.

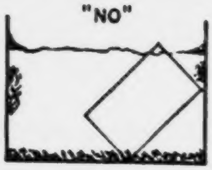
Sampling point should be readily accessible and adequate safety precautions should be observed.



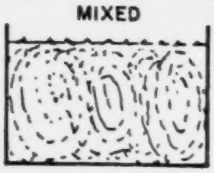
MLSS samples should be collected at a convenient distance from the sides of the aeration basin.



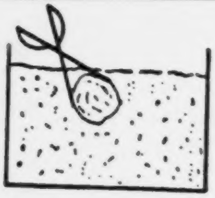
No deposits or materials should be collected from the side walls or the water surface.



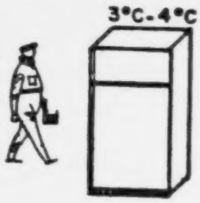
Sample must be taken where the wastewater is mixed and of uniform composition.



Large or unusual particles should not be collected with routine samples.



Sample should be delivered and analyzed as soon as possible. Stored samples must be refrigerated at 3 to 4° C.



WASTEWATER SAMPLING GUIDELINES

FIGURE IV-1

Sample collection should be conducted systematically at various sampling locations during the flow sequence through the plant. Grab sampling times may be systematically staggered to account for the respective hydraulic detention time of each unit process. In this manner, a slug of water may be theoretically followed through the treatment plant. For example, if the hydraulic detention period through a particular unit process unit is two hours, then the grab sample of the effluent from this unit should be collected two hours after the influent sample. In this manner, the samples can be assumed to be representative of the wastewater before and after treatment.

Composite Samples

24-Hour composites are the best for determining organic loading and performance.

Composite samples generally represent the wastewater characteristics over a specified period of time. The ideal procedure incorporates the use of 24-hour composite samples consisting of hourly grab samples proportioned to the flow at the time of sampling. This procedure is only feasible in treatment facilities with 24-hour attendance or where automatic samples are warranted. Adequate results, however, can generally be obtained from analysis of composite samples collected over a shorter period. In those facilities where automatic samplers are not available, collection of composite samples during the number of shifts worked would be sufficient as long as peak flow periods are included. A total composited sample volume of approximately three liters is generally sufficient to perform the routine process control tests.

MLSS Sampling

Take MLSS samples at same time and location each day.

MLSS samples taken to develop an estimate of the amount of solids in the aeration tank should always be taken at the same time of the day and should always be taken from several places along the tank section. Ordinarily only one solids analysis need be conducted on a composite made up of samples taken from every quadrant of every tank. Analysis of individual samples should also be conducted occasionally to develop additional information about the condition of the process. Composites from aeration tanks of different size can be prepared by first combining equal volume samples from each tank quadrant, and then combining the tank composites.

How to make up a MLSS sample when multiple tanks are in operation.

When samples of the mixed liquor are taken, a composite should be prepared from samples withdrawn from all the tanks under aeration. If any of the aeration tanks are of different size, the sample should be taken in proportion to tank size. Occasionally, the MLSS concentration in each tank should be measured. For example, suppose an operator is to collect a MLSS sample which is to be representative of a complete mix plant having 3 aeration tanks with a volume of 0.4 mil. gal. and 3 new aeration tanks having a volume of 0.6 mil. gal. One liter of MLSS has already been collected from each tank. How much should be taken from each of the six one liter samples to prepare a 1 liter composite that is representative of all the aeration tanks?

$$\text{Sample volume per tank, liters} = \frac{(\text{Tank Vol., mg})(\text{Composite Vol., liters})}{\text{Total Vol. of all tanks, mg}}$$

$$\text{For the 0.4 mil gal tanks, volume} = \frac{(0.4)(1.0\ \text{liter})}{(3 \times 0.4) + (3 \times 0.6)} = 0.13\ \text{liter (130 ml)}$$

$$\text{For the 0.6 mil gal tanks, volume} = \frac{(0.6)\quad(1.0\ \text{liter})}{(3 \times 0.4) + (3 \times 0.6)} = 0.2\ \text{liters (200 ml)}$$

$$\text{Total Volume} = (3 \times 0.13) + (3 \times 0.2) = 0.99\ \text{liters (990 ml)}$$

Composite sampling for processes operating in the step feed and sludge reaeration modes should be conducted in the same manner described above and shown in Figure IV-2.

How to composite MLSS samples to be proprotional with flow.

Once the composite sample is made to represent all of the tanks it should be proportioned to the aeration influent flow rate (either raw wastewater or primary effluent flow rate). As stated above, composite samples represent wastewater characteristics over a specified period of time. Generally a total composited sample of 3 liters is adequate to perform routine process control tests. Therefore, the total amount of sample required, the number of samples required, the rate of flow at the time of sampling, and the estimated average daily flow rate, can be used to calculate the amount of representative aeration tank sample to be composited during each sampling period to represent the daily flow. This may be calculated using the following equation.

$$\text{Amount of sample to collect, ml} = \frac{(\text{Rate of flow, mgd @ time of sampling})(\text{Total sample required, ml})}{(\text{Number of samples collected})(\text{Average daily flow, mgd})}$$

Example Calculation

A. Data Required
  1. Rate of flow at time of sample collection = 1.5 mgd
  2. Total sample volume required, Note ml = (liters) (1000) = 3 liters or 3000 ml
  3. Number of samples to be collected = 8
  4. Average daily flow = 0.9 mgd

B. Determine the amount of sample to be collected for the present flow rate in milliliters.

Calculation for composite sampling.

$$\text{Amount of sample to collect, ml} = \frac{(\text{Rate of flow, mgd})\,(\text{Total sample required, ml})}{(\text{Number of samples})\,(\text{Ave. daily flow, mgd})}$$

$$= \frac{(1.5\text{ mgd})\,(3000\text{ ml})}{(8)\,(0.9\text{ mgd})}$$

$$= 625\text{ ml}$$

This equation may also be used to composite other samples taken from the plant.

Laboratory Control Program

Lab control requires adequate facilities and technical skills.

The specific laboratory tests and frequency which they are performed for process control and performance evaluation will vary from plant to plant depending on the variation of the activated sludge process, its size, laboratory facilities provided, process control method used, available manpower, and technical skills. A typical sampling and testing program for an activated sludge process is presented on Figure IV-2.

4.03 LABORATORY CONTROL TESTS

Laboratory analyses are the tools of process control.

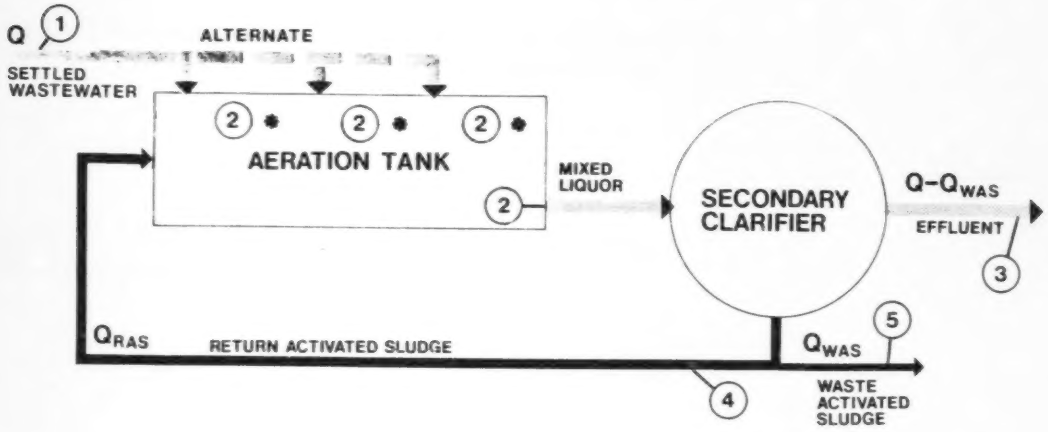
This section of the manual is provided to increase understanding and to develop an appreciation of laboratory control tests.

Sampling and analyses must be increased when the process is upset.

The tests discussed are those necessary for routine process control when the biological system is operating properly. Additional analyses and increased frequency of analysis for the routine analysis may be required for abnormal conditions. Specific suggestions are made for abnormal operation in Section I, "TROUBLESHOOTING." However, the operator must rely upon his own judgement to determine which analyses he needs to conduct to supply the information that he desires.

Typical worksheets provided.

Typical worksheets have been provided in Appendix A to assist the operator in developing systematic data collection, calculation, and recording. Precautionary procedures are presented for each of the tests presented in this section to make the operator aware of the common pitfalls. Except where a specific note is made, all analyses are referenced to the fourteenth edition of "Standard Methods for the Examination of Water and Wastewater".


Q ①
SETTLED WASTEWATER
ALTERNATE
② ✱ ② ✱ ② ✱
AERATION TANK
②
MIXED LIQUOR
SECONDARY CLARIFIER
Q-Q$_{WAS}$
EFFLUENT
③
⑤
Q$_{WAS}$
Q$_{RAS}$
RETURN ACTIVATED SLUDGE
④
WASTE ACTIVATED SLUDGE

TYPICAL ACTIVATED SLUDGE PLANT

DESCRIPTION	SETTLED SEWAGE OR RAW SEWAGE	AERATION BASIN	SECONDARY CLARIFIER EFFLUENT	RETURN ACTIVATED SLUDGE	WASTE ACTIVATED SLUDGE	SECONDARY CLARIFIER	FREQUENCY	TYPE OF SAMPLE	METHOD OF TEST	APPLICATION OF TEST
FLOW	CR		CR	CR	CR		–	–	–	P
BOD	☒		☒				3/W	C	AM	P
COD	☒		☒				3/W	C	AM	P
SUSPENDED SOLIDS TOTAL ✱	☒	☒	☒	☒	☒		3/W	C	AM	P
SUSPENDED SOLIDS VOLATILE ✱	☒	☒	☒	☒	☒		3/W	C	AM	P
NITROGEN-KJELDAHL	☒		☒				2/W	C	AM	P
AMMONIA	☒		☒				2/W	C	AM	P
NITRITE			☒				2/W	G	AM	P
NITRATE			☒				2/W	C	AM	P
PHOSPHORUS	☒		☒				2/W	C	AM	P
30 MIN. SETTLING		☐					D	C&2G	AM	P
DO		☒	☒				D	G	AM	P
pH	☒	☒	☒				D	G	AM	S
TEMPERATURE	☒	☒	☒				D	G	AM	S
AIR INPUT-SCFM		CR					D	–	–	P
SLUDGE BLANKET						MM	D	–	PM	P
MICROSCOPIC EXAMINATION		☐					1/W	G	–	P
LOCATION OF SAMPLE	①	②✱	③	④	⑤					

CODE DESCRIPTION			
☐	SAMPLE	S	SURVEILLANCE
☒	TEST RESULTS CALCULATED	W	WEEK
②	DENOTES SAMPLE LOCATION	AM	ANALYTICAL MEASUREMENT
C	COMPOSITE	CR	CONTINUOUSLY RECORDED AND TOTALIZED
D	DAILY	MM	MAKE MEASUREMENT
G	GRAB	PM	PHYSICAL MEASUREMENT
P	PROCESS CONTROL		

✱ SAMPLING LOCATIONS FOR STEP FEED AND SLUDGE REAERATION

TYPICAL SAMPLING AND TESTING PROGRAM FOR ACTIVATED SLUDGE

FIGURE IV-2

Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand is determined by incubating a sample of known volume in the presence of microorganisms, excess nutrients, and dissolved oxygen. A properly conducted BOD analysis will have organic matter as the growth limiting substance. If oxygen is limiting, the analysis is not meaningful.

The 5-day BOD.

The BOD is an index of the amount of oxygen that will be consumed by the decomposition of the organic matter in a wastewater. The analysis consists of measuring the initial dissolved oxygen concentration, incubation for five days at 20° C, and measuring the final dissolved oxygen. The difference in dissolved oxygen concentration corrected for the initial dilution and sample volume is called the BOD. The BOD test is related to both the organic loading upon the biological process as well as the removal efficiency of the process. The difference between the BOD applied and the BOD leaving the process is equal to the BOD removed by the process. This difference is part of the data required to determine the loading upon the process. For example, the organic loading upon the activated sludge process is expressed as the pounds BOD applied per day pound of mixed liquor volatile suspended solids (lbs BOD/day/lb MLVSS). The efficiency of the process is determined by the following formula:

$$\frac{\text{BOD applied, lb/day - BOD leaving, lb/day} \times 100}{\text{BOD applied, lb/day}} = \text{the removal efficiency, \%}$$

In this determination, the aeration tank and clarifier are considered, as one system.

Precautionary Procedures

When performing BOD analyses the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

Minimum of two dilutions, at least 2 mg/l D.O. used—must be at least 2 mg/l left after 5-days.

1) A minimum of two dilutions per sample should be used. Only analyses with oxygen depeltions of greater than 2 mg/l but with no less than a residual of 2.0 mg/l after five days of incubation at 20° C should be used to calculate the BOD. Generally, the highest value calculated should be used to represent the BOD.

Mix samples well.

2. Samples should be well mixed before the dilutions are made. A wide tip pipette should be used for making the dilutions. The wide tip does not clog with suspended solids.

Avoid aeration during bottle filling.

3 .Samples and the dilution water must be carefully added to the BOD bottle to avoid aeration and the possibility of entraining bubbles in the solution.

Note 5-Days mean 120 Hours.

4) The BOD incubator *must* be maintained at 20° ± 1° C for the entire 5 day (Note: 120 hours) period. Record the temperature of the incubator from a NBS certified thermometer placed in a beaker of water in the incubator.

Toxic slide.

5) If the BOD value of the more dilute sample is always greater, this may indicate that there is some toxic material in the wastewater, which is inhibiting the bacteria. A series of dilutions should be set up and run. If the BOD is increasing with higher dilution, this may indicate a condition known as a toxic slide. Further analyses should be conducted to determine the nature of the toxic material, and if it appears that the concentration of the toxicant is significant, efforts should be initiated to identify the source and reduce the concentration of the toxicant in the wastewater.

Primary standard made from glucose.

6) Use of a primary standard is strongly recommended. The standard should be made of glucose—glutamic acid mixture—and it should be made up at a BOD near those levels in the treatment plant influent. The primary standard should be made up and analyzed weekly. Any significant variation (more than ± 20%) should cause the operator to be suspicious. Efforts should be undertaken to review the laboratory procedure, and find out what is causing the problem. Each operator should analyze the standard and the results should be within ± 10%. Operators not falling within this range should review their laboratory techniques, and make the appropriate adjustments.

Use allythiourea to inhibit nitrifiers.

7) Wastewaters that have been partially nitrified may produce high BOD results. The increased oxygen demand results from the oxidation of ammonia to nitrate. The use of allylthiourea in the dilution water will inhibit the nitrifiers and alleviate this problem.

Chemical Oxygen Demand (COD)

COD is fast and reproducible.

The COD is an estimate of the total oxygen demand that results from the degradable organic matter. The analysis consists of oxidizing the organic matter with potassium dichromate in a heated strongly acidic solution.

While the BOD analysis is an index of the biodegradable organic matter, it is not very useful for process control because of the five day lag in time. The COD test is rapid (3-4 hours); it is not subject to interferences from toxic materials; and it is not affected by ammonia oxidation.

The COD is better for process control.

The COD removal of a biological process is directly relatable to the amount of biological growth that can result from this removal. The COD analysis suffers from the disadvantage that it does not measure the *rate* of or biodegrability of matter removal, and therefore it is difficult to predict the effects of effluents on the oxygen resources of receiving waters and the treatability of a particular wastewater.

Precautionary Procedures

When performing the COD test, the following procedures should be followed in conjunction with those outlined in Standard Methods.

The analyst must establish his variability.

1) Initially, the analyst should run triplicate samples to establish the variability of his analyses. Once this variability is established, samples can be analyzed without replication.

2) Use a wide tip pipette to ensure that a representative sample is taken.
3) Glassware used for the COD analyses must be washed with hydrochloric acid, hot washed, and rinsed three times with distilled water.
4) Extreme caution and safety precautions should be practiced when handling the chemical reagents for the test. Goggles, a rubberized apron and asbestos gloves are essential equipment.
5) If a sample mixture turns green during or immediately following the heating period, the analysis is not valid and should be reexamined in a more dilute sample. If the problem reoccurs, then the laboratory technique should be reevaluated and the sample should be checked for likely interferences, such as high chloride concentration or the presence of a strong base.
6) A primary standard consisting of potassium acid phtalate should be analyzed on a weekly basis to ensure that the analyses are consistent. The COD concentration of the standard should be near the level of the COD of the wastewater. (See Standard Methods.)

Soluble COD and BOD

Soluble COD and BOD.

The discussions on BOD and COD have been limited to the measurement of the total COD and BOD. The soluble BOD and COD are more meaningful for measuring performance (conversion of food to cell growth). The soluble BOD or COD is determined in exactly the manner described above, except that the sample is filtered through a membrane filter prior to the analysis. The use of this filtering apparatus is discussed under the suspended matter analysis.

Settleable Matter

The settleable matter test (also known as the Imhoff Cone Test) is a measure of the volume of solid matter that settles to the bottom of an Imhoff cone in one hour. The volume of settled solids is read as milliliters per liter (ml/l) directly from the graduations at the bottom of the Imhoff cone.

This test is of value in providing a quick and efficient check of a sedimentation unit. Additionally, a rough estimate of the volume of solids removed by the sedimentation unit can be made. Only a trace of settleable solids should remain in the secondary effluent. Poor settleable matter removal may indicate the following related problems which may occur in sedimentation basins:

Symptoms highlighted by settleability test.

Primary and Secondary
1) Hydraulic overload.
2) Irregular flow distributions to multiple units.
3) Excessively high velocity currents.
4) Effluent weirs of uneven height—short circuiting.
5) Improper sampling technique.
6) Improper raw sludge removal rates.

Secondary only

1) Biological upset.
2) Improper RAS pumping rate.

Precautionary Procedures

When performing the settleable matter test, the following procedures should be followed in conjunction with those outlined in Standard Methods.

1) Take a sample volume greater than one liter.
2) Use grab samples for this analysis.
3) Fill the Imhoff cone exactly to the one liter mark in one rapid pouring without stopping.
4) After the sample has settled for 45 minutes, either gently tap the sides of the cone or gently spin the cone between the palms of your hands to settle those solids adhering to the sides of the cone above the compacted settled layer at the bottom of the cone.
5) Read and record the volume of settled matter (ml/l) at the end of one hour. Read the graduation at the average solids depth and not at a peak or void area on the surface of the settled solids.

Total Suspended Matter

Measure of the filterable solids.

The suspended matter test refers to the solids in suspension that can be removed by standard filtering laboratory procedures. The suspended matter is determined by filtering a known volume of sample through a weighed glass-fiber or membrane filter disc in an appropriate filtering apparatus. The filter with the entrapped solids is oven-dried at 103° - 105° C and then cooled in a desiccator and subsequently weighed. The increase in filter weight represents the suspended matter.

The significance of the suspended matter test is generally dependent on the type of treatment process and the location of measurement within the process application. Results of the test have the following uses in process control:

Use of this test.

1) Evaluating the organic strength of the wastewater.
2) Evaluating clarifier solids loading.
3) Determine the sludge recycle rate by calculation.
4) Calculating clarifier solids capture.
5) Estimating the solids inventory.

Volatile Suspended Matter

A measure of the organic matter—proportional to the microorganism concentration in the mixed liquor.

The volatile suspended soilds test is performed by volatilizing the non-filterable residue from the total suspended solids test. This volatilization is done by burning in a furnace at about 550° C. The results of this test indicate the amount of volatile and nonvolatile solids contained in the sample.

This test is an index of the quantity of microorganisms in the activated sludge. The test has the same significance as the total suspended matter test with two additional applications which are the determination of F/M ratios and the MLSS levels to be maintained in the aeration basin of an activated sludge plant.

Precautionary Procedures

When performing the suspended matter test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) The sample must be thoroughly mixed prior to taking a sample aliquot.

Use wide tipped pipette.

2) Do not use a small-tipped pipette to measure the sample aiquot. A wide-tipped pipette should be utilized to permit passage of the larger solids and to facilitate rinsing. An alternate method of obtaining a sample aliquot would be to pour it into a graduated cylinder.
3) Rinse all adhering solids from graduate (or pipette) with distilled water. Pour rinse water through the filter.
4) Test results that appear faulty or questionable should be disregarded.

Temperature between 103-105° C.

5) It is important to always maintain a temperature of between 103 - 105° C in the drying oven. The temperature must be monitored and recorded in a record book.
6) Be sure that the filter is properly seated in the filtration apparatus before pouring the sample. This is easily accomplished by wetting the filter with distilled water, then applying vacuum to the filtration apparatus.
7) Samples containing high solids levels may require more than one hour to completely dry. This is especially true of return sludge samples.
8) Be consistent in the length of time the filter apparatus and paper are allowed to cool in the dessicator both before and after filtering.
9) Use Whatman GF/C filters and a millipore filter apparatus with sintered glass seat for this analysis.

Nitrite Nitrogen

NO_2 partially oxidized form of nitrogen

Nitrite (NO_2) is an intermediate oxidation state of nitrogen between ammonia nitrogen and nitrate nitrogen. Nitrite is transatory and readily amendable to both bacterial oxidation to nitrate or reduction to nitrogen gas depending upon environmental factors such as dissolved oxygen and microbial conditions.

High NO_2 concentrations imply incomplete nitrification

The nitrite concentration can be used to monitor how well nitrification is progressing in a treatment process. High nitrite concentrations indicate incomplete nitrification, and could lead to problems, such as high chlorine and oxygen demands.

Precautionary Procedures

When performing the nitrite nitrogen test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) Use extreme caution in handling the chemical reagents to avoid injury or damaged clothing.

Analyze as soon as possible.

2) Due to the instability of nitrite (NO_2), the composite samples used for the nitrite analysis should be preserved by one of the following methods: (a) freezing, or (b) addition of 5 ml of chloroform/l of sample. In general it is advisable to analyze only fresh grab samples for nitrite.

Sample must be cool.

3) The samples must be cool when the analysis is performed or erroneous results will be measured.

4) Deviation from standard procedure may yield erroneous results. Be consistent in your laboratory technique.

Nitrate Nitrogen

Nitrate is seldom found in raw wastewater or primary effluent, because facultative microorganisms can readily use nitrate as an oxygen source. In the biological treatment process, the ammonia nitrogen can be microbiologically oxidized to nitrite and then to nitrate depending on the microorgansims present and the environmental factors such as pH, temperature, and dissolved oxygen.

Secondary effluent may contain from 0 to 50 mg/l nitrate nitrogen depending on the total nitrogen content in the raw wastewater and conditions of treatment. Activated sludge systems that have a long MCRT (usually 10 days or more) and adequate oxygen can also produce a nitrified effluent.

Precautionary Procedures

When performing the nitrate nitrogen test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

Use the Brucine Method.

1) Use the Brucine method for routine analysis.
2) Analyze the sample as soon as possible to avoid bacterial reduction of the nitrate.
3) Preserve samples that cannot be analyzed immediately by either freezing or by the addition of 5 ml of chloroform/l of sample.

Total Kjeldahl Nitrogen (TKN)

TKN measures organic and ammonia nitrogen.

This test measures the ammonia and organic nitrogen but not the nitrite or nitrate nitrogen. The sample is digested with acid and catalysts that convert the organic nitrogen to ammonia nitrogen. The ammonia is then distilled off into a boric acid solution and measured by either a colorimetric analysis called nesslerization or by titration.

Most nitrogen in raw wastewaters in this form.

In raw wastewater, nitrogen is primarily found as organic and ammonia nitrogen depending on the degree of decomposition. As decomposition increases, the organic nitrogen is biologically decomposed (ammonified) to ammonia nitrogen.

The results of this test are valuable because it can be used to:

1) Evaluate the performance of a treatment process designed to nitrify.
2) Evaluate nutrient (nitrogen) deficiency.
3) Evaluate oxygen requirements for activated sludge.

Precautionary Procedures

When performing the Total Kjeldahl Nitrogen test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods:

Do not breathe the fumes.

1) Use extreme caution in handling the reagents to avoid injury.
2) Perform the digestion step under a ventilated hood. Do not breathe in the fumes given off during digestion.
3) The TKN test may be performed on the same composite samples as for the BOD and Suspended matter tests. The samples should be preserved by refrigeration at 3 to 4° C for not more than 24 hours.
4) Deviation from standard procedures may yield erroneous results. Be consistent in lab technique.

Ammonia Nitrogen

This test measures the nitrogen present in the wastewater as ammonia. Ammonia nitrogen in domestic wastewater is generally between 10 and 40 mg/l. Primary treatment may increase the ammonia nitrogen content slightly due to decomposition of some protein compounds during treatment. In secondary treatment process, ammonia can be oxidized to nitrite then to nitrate in varying degrees depending on factors, such as the residence time of the microorganisms, wastewater temperature, and oxygen reliability.

A measure of the form of nitrogen that causes high chlorine demands and fish toxicity.

The significance of this test is associated with the oxygen demand required to oxidize ammonia in the biological treatment process or receiving stream. Theoretically, the oxidation of one pound of ammonia nitrogen requires 4.6 pounds of oxygen. This test is also valuable in evaluating the performance of a treatment process designed to nitrify. Other significant problems relating to ammonia are high chlorine demands, fish toxicity, and high oxygen demand in receiving waters.

Precautionary Procedures

When performing the Ammonia Nitrogen test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) Use extreme caution in handling the chemical reagents to avoid injury or damaged clothing.
2) Deviation from standard procedures may yield erroneous results. Consistency in laboratory techniques is essential.

30-Minute Settling Test

An important measure of mixed liquor settling.

Observe at 5 min intervals for first 30 min, 10 min thereafter.

Stirring can improve results.

The 30-minute settling test of MLSS provides an index of the activated sludge settling and compaction characteristics in the secondary clarifier. The test, in itself, is simple to perform and requires only a graduated glass cylinder and a clock. It is performed by transferring a thoroughly mixed one-liter sample of mixed liquor to a one liter graduated cylinder and then recording the milliliters of sludge settled in the one-liter graduated cylinder at five minute intervals for the first 30 minutes and then at ten minute intervals up to one hour. This test can also be conducted with stirring, and the operator should try both methods to see which most closely models his sedimentation results in the clarifier.

Related to the SVI.

This test indicates how well the activated sludge mixed liquor concentrates and compacts. The usual index of sludge settleability and compaction is the Sludge Volume Index (SVI) or its reciprocal the Sludge Density Index (SDI) which are based on the sludge level at the end of the 30-minute period. Some results, however emphasize that an SVI of 100 (SDI of 1.0) is indicative of a well functioning activated sludge plant. This may not necessarily be true because these indices represent only the 30-minute settling and do not necessarily account for the clarity of the liquid above the sludge. Observations should be made during the 30-minute test to determine whether the sludge particles are agglomerating well, settling uniformly, and leaving a clear liquid or whether sludge particles are settling rapidly and leaving a cloudy liquid above. The latter behavior is indicative of several operational problems which are discussed in Section 2.05. During the 30-minute test, a well settling sludge will normally settle to approximately half of its original volume in the first 5 to 10 minutes.

Precautionary Procedures

When performing the 30-minute settling test, the following procedures should be followed in conjunction with procedures outlined in Standard Methods.

1) A morning and afternoon grab sample (or two samples per shift) should be tested for settleability.
2) Grab samples should be taken during peak as well as average flow periods.
3) Each sample should be collected consistently and at the same location.
3) Vigorous mixing and pouring of sample should be avoided.
5) Be certain to fill the settling cylinder exactly to the one-liter mark.
6) Record time test is set up and temperatures of sample.
7) Record settling level every five minutes for the first 30 minutes and every 10 minutes for the second 30-minute period.

Observations During Test

Important to observe results with time—Do not read only at 30 minutes.

An important factor in running the 30-minute settling test is to observe the settling and compaction characteristics of the MLSS. Often operators walk off after setting up the test and come back to read and record the settling level at the end of 30 minutes. In doing this, they may miss important information by not observing how the sludge settles. Use of the 30-

minute test only to calculate the SVI or SDI does not provide the maximum benefit for process control. The operator should attempt to record the following observations during the test so that correlations to other laboratory control tests used for process control can be made:

A. **First Five to Ten Minutes**
   - *1) Do sludge particles agglomerate while forming blanket?
   - *2) Does sludge compact slowly and uniformly, leaving a clear liquid?
     or
   - 3) Do sludge particles fall through a cloudy liquid?
   - 4) How much and what type of straggler floc, if any, remains in the liquid?

B. **End of 30 Minutes**
   - *1) Has the sludge floc compacted to the appearance of looking crisp with sharp edges and somewhat like a sponge? or,
   - 2) Does the floc look feather-edged fluffy and somehwat homogenous?

C. **End of 60 Minutes**
   - 1) Has any settled sludge floated to the surface of the cylinder?
   - *2) Did it take two to four hours for the sludge to split or float to the surface?
   - 3) These observations provide a check on the final clarifier sludge blanket charcteristics and removal rates in relation to sludge detention time in the clarifier.

*A well settling sludge will have the characteristics of Items A-1 and A-2, B-1, and C-2.

Total Phosphorus

Phosphorus is one of the nutrients essential to biological growth in secondary treatment processes. Most wastewaters have more phosphorus available then is required for biological growth and assimilation of the carbonaceous BOD. A deficiency of phosphorus may result from high waste loading from industries, such as canneries which generally have wastes that are high in carbohydrates and low in nutrients. Such a phosphorus deficiency may limit biological growth and lead to poor BOD removals.

Typical raw domestic wastewater contains approximately 10 mg/l of phosphorus of which 20 to 30 percent may be removed by the growth of microorganisms which are wasted from the process. Greater removals may be obtained by various processes involving addition of a metal ion such as iron or aluminum to chemically precipitate iron or aluminum phosphate. Other removal processes involve pH adjustment by addition of lime or other means and chemical precipitation of a calcium phosphate.

Precautionary Procedures

When performing the total phosphorus test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) Use extreme caution in handling the chemical reagents to avoid injury or damaged clothing.
2) Record specific procedures used for pretreatment of sample and measurement of phosphorus concentration with test results. Also, clearly indicate the expression of the test results, P or PO_4. (Note: 1.00 mg/l P equals 3.06 mg/l PO_4.)
3) Deviation from standard procedure may yield erroneous results. Be consistent in your laboratory technique.

Dissolved Oxygen

An important parameter.

Dissolved oxygen (DO) is that oxygen dissolved in liquid and is usually expressed as milligrams per liter (mg/l). There are various types of tests to determine the DO content of water. Generally, the iodometic methods and the membrane electrode (DO probe) are best suited for the domestic wastewater application. The azide modification of the iodometric method (also known as Winkler Method) is recommended for most wastewater and stream samples. When determining the DO in activated sludge mixtures (MLSS and RAS), and other biological flocs which have a high oxygen utilization rate, the copper sulfate-sulfamic acid flocculation modification should precede the azide modification to retard biological activity and to flocculate suspended solids. The membrane electrode method is becoming increasingly more popular because of its speed, ease of operation, and adaptability to process control instrumentation. Often, the membrane electrodes are used for continuous monitoring and control of DO in activated sludge units. The membrane electrodes must be properly maintained and calibrated on a daily basis to ensure that their measurements are accurate and usable for process control.

DO measurements can be used to control aeration.

The significance of the DO test in process control is in its measurement of the dissolved oxygen available for and essential to aerobic decomposition of the organic matter; otherwise, anaerobic decomposition may occur with the possible development of nuisance conditions. In the activated sludge process, the DO test is used to monitor the aeration process as a basis for control of the air supply rates, in order to maintain a desired DO residual, while avoiding overaeration and power wastage. The DO test is also used in the determination of BOD as discussed previously. Fish and most aquatic life require dissolved oxygen to sustain their existence and the DO test is an important measurement in plant effluents and receiving water quality.

Precautionary Procedures

When performing the DO test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) Use extreme caution in handling the chemical reagents to avoid injury or damaged clothing.

Use special care in sampling.

2) The use of special DO sampling equipment is preferable for collecting samples. The samples should be taken with the sample container completely immersed and without aeration of the sample or entrapment of any air bubbles.

Perform immediately after sampling.

3) Perform DO test immediately following collection of sample.
4) The following substances will interfere in the azide modification of the iodometric DO analysis: iron salts, organic matter, excessive suspended matter, sulfide, sulfur dioxide, residual chlorine, chromium, and cynaide.

Hydrogen Ion Concentration (pH)

An important measure for the microorganism.

The intensity of acidity or alkalinity of a solution is numerically expressed by its pH. A pH value of 7.0 is neutral, while values 7 to 14 are alkaline and values 0 to 7 are acid. pH can be measured colorimetrically or electrometically. The electrometric method (pH meter) is preferred in all applications because it is not as subject to interference by color, tubidity, colloidal matter, various oxidants and reductants as is the less expensive colorimetric method.

The pH measurements are valuable in process control because pH is one of the environmental factors that affect the activity and health of microorganisms. Sudden changes or abnormal pH values may be indicative of an adverse industrial discharge of a strongly acid or alkaline waste. Such discharge are detrimental to biological processes as well as to the collection system and treatment equipment, and should be either stopped or neutralized prior to discharge. Generally, the pH of the secondary effluent will be close to 7. A pH drop may be noticeable in a biological process achieving nitrification because alkalinity is destroyed and carbon dioxide is produced during the nitrification process.

Precautionary Procedures

When performing the pH test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

Use grab samples—analyze immediately.

1) Grab samples should be used for the pH measurement. The pH test should be performed on the samples immediately following collection before the temperature or dissolved gas content can change significantly. Do not heat or stir the pH sample as a change in temperature or dissolved gas content will affect the pH value.
2) Do not contaminate the buffer by pouring the used buffer solution back into the buffer container.

Calibrate the pH meter daily.

3) Calibrate the pH meter daily with a buffer solution of approximately the same temperature and pH as the sample to be tested. Adjust the pH meter's temperature compensator for each pH measurement.

Exercise extreme care with electrodes.

4) Avoid fouling the electrodes with oil or grease.
5) Erratic results or drifting should prompt an investigation of the electrodes.

Temperature

Temperature affects growth of microorganisms.

In process control, accurate temperature measurements are helpful in evaluating process performance because temperature is one of the most important factors affecting microbial growth. Generally stated, the rate of microbial growth doubles for every 10° C increase in temperature within the specific temperature range of the microbe. Temperature measurements can be helfpul in detecting infiltration/inflow problems and illegal industrial discharges. Thermometers are calibrated for either total immersion or partial immersion. A thermometer calibrated for total immersion must be completely immersed in the wastewater sample to give a correct reading, while a partial-immersion thermometer must be immersed in the sample to the depth of the etched circle around the stem for a correct reading.

If a Fahrenheit thermometer is used, its reading may be converted to Centigrade by following formula:

$$^\circ C = \frac{5}{9} (^\circ F - 32^\circ)$$

Precautionary Procedures

Measure immediately.

When obtaining the temperature of a sample, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) To attain truly representative temperature measurement, it is necessary either to take the temperature reading at the point of sampling or immediately following sample collection. A large sample volume should be used to avoid a temperature change during the measurement.
2) The accuracy of the thermometer used should be occasionally verified against a precision thermometer certified by the National Bureau of Standards (NBS).
3) The thermometer should be left in the sample while it is read.

Microscopic Examination

A useful tool.

Microscopic examination of the MLSS can be a significant aid in the evaluation of the activated sludge process. The presence of various microorganisms within the sludge floc can rapidly indicate good or poor treatment. The most important of these microorganisms are the heterotropic and autotrophic bacteria which are responsible for purifying the wastewater. In addition, protozoa play an important role in clarifying the wastewater and act as indicators of the degree of treatment. The presence of rotifiers is also an indicator of effluent stability.

The important protists.

A predominance of protozoa (ciliates) and rotifiers in the MLSS is a sign of good sludge quality. The treatment under these conditions, with proper RAS, WAS and aeration rates, can be expected to produce effluent BOD concentrations of less then 10 mg/l.

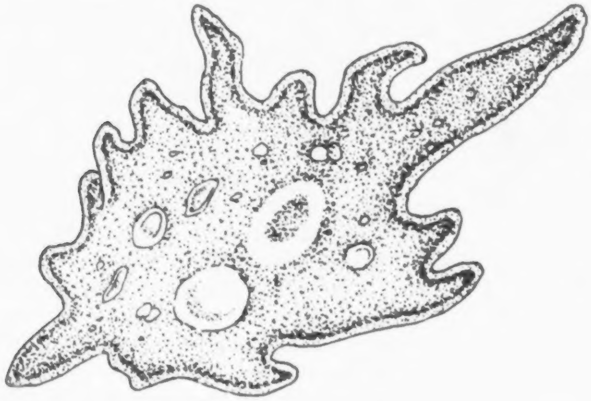
Inversely, a predominance of filamentous organisms and a limited number of ciliates is characteristic of a poor quality activated sludge. This condition is commonly associated with a sludge that settles poorly. The sludge floc is usually light and fluffy because it has a low density. There are many other organisms such as nematodes (worms) and waterborne insect larvae which may be found; however, these do not significantly affect the quality of treatment.

The microorganisms which are important to the operator are the protozoa and rotifers. As discussed previously, the protozoa eat the bacteria and help to provide a clear effluent. Basically, the operator should be concerned with three groups of protozoa, each of which have significance in the treatment of wastewater. These groups include the following:

1) Amoeboids
2) Flagellates
3) Ciliates

Amoeboids (Figure IV-3)

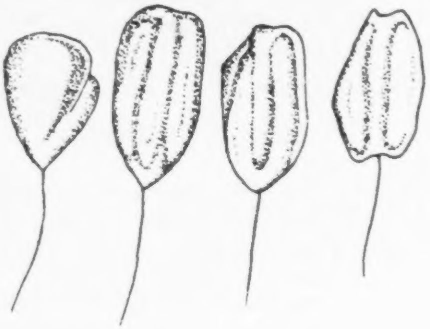
The cell membranes of Amoeboids are extremely flexible; and the mobility of these organisms is created by the movement of protoplasm within the cell. Food matter is ingested by absorption through the cell membrane. Amoeboids may predominate in the MLSS floc during start-up periods of the activated sludge process or when the process is recovering from an upset condition.



AMOEBOIDS
FIGURE IV-3

Flagellates (Figure IV-4)

These organisms are characterized by the tail (Flagella) which extends from their round or elliptical cell configuration. Their mobility is created by a whipping motion of the tail, which allows them to move with somewhat of a corkscrew motion. Flagellate predominance may be associated with a light-dispersed MLSS floc, a low population of bacteria, and a high organic load (BOD). As a more dense sludge floc develops, the flagellate predominance will decrease with an increase of bacteria. When the flagellates no longer are able to successfully compete for the available food supply, their population decreases to the point of insignificance.



FLAGELLATES

FIGURE IV-4

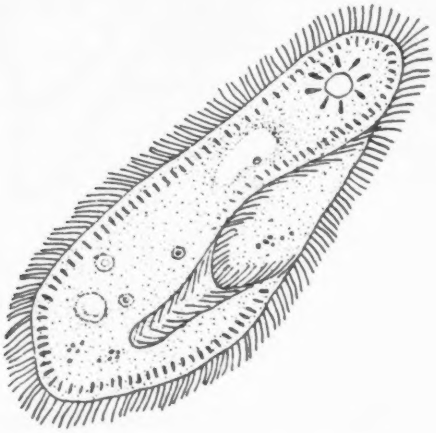
Ciliates

These organisms are characterized by the rotating hair-like membrane (cilia) which cover all or part of their cell membrane. Their mobility is created by the movement of the cilia, and the cilia around the gullet are utilized for the intake of food. Ciliates may predominate during the period of fair to good settling of the activated sludge.

They are considerably larger than flagellates and for the purposes of microscopic examination may be classified into two basic groups, which are the free swimming and the stalked ciliates.

Free Swimming Ciliates (Figure IV-5)

Free swimming ciliates are usually apparent when there is a large number of bacteria in the activated sludge. These organisms feed or graze on the bacteria and clarify the effluent. Therefore, their presence is generally indicative of a treatment process that is approaching an optimum degree of treatment. A relative predominance of flagellates indicates decreased treatment efficiency and the MCRT of the system should be increased to maintain a relative predominance of free swimmers, stalked ciliates and higher forms of organisms such as rotifers.

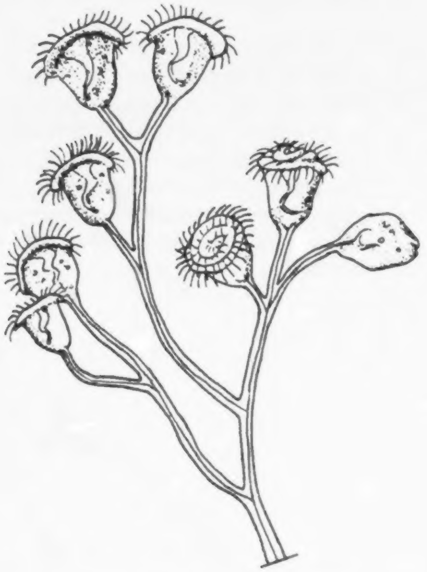


FREE SWIMMING CILIATES

FIGURE IV-5

Stalked Ciliates (Figure IV-6)

These organisms are frequently present when the free swimmers are unable to compete for the available food. A relative predominance of these organisms along with rotifers will indicate a stable and efficiently operating process.



STALKED CILIATES

FIGURE IV-6

Evaluation of Microscopic Examination

Changes in MCRT are reflected in the appearance of the mixed liquor.

Observation of microorganism activity and predominance in the activated sludge can provide guidance in making process control adjustments. Study of Figure IV-7 can be used to assist the operator with the decision of increasing or decreasing the MCRT based on the relative predominance of ciliates and rotifers in the MLSS. The decline of ciliates and rotifers is frequently indicative of a poorly settling sludge. These observations make it possible to detect a change in organic or chemical loading before an upset occurs. These changes can be correlated with observations of the settling characteristics of the MLSS in the 30-minute settling test, and by calculation of the F/M. If the other tests confirm these observations, adjustments to the MLSS should be made to alleviate the problem.

Relative predominance of rotifers and ciliates indicates process stability.

In summary, relative predominance of ciliates and rotifers are an indication of process stability. This predominance is associated with the efficiency of treatment under various loading conditions. An increase or decrease in the predominance of these organisms may be indicative of process upset before there is a major effect on process performance.

Use an inexpensive camera to record the mixed liquor appearance.

A great deal of information can be provided if photographic records of sludge conditions are kept in a systematic and well documented manner. Inexpensive (approximately $100) Polaroid cameras are available for this purpose, and it is strongly recommended that a camera of this type be obtained along with the microscope. These photographic records can be used to anticipate seasonal variation or conditions of unusual operation.

Selection of a Microscope*

Features which should be considered when selecting a microscope include the following:

1) Built-in illumination or an external system which allows variations of light intensity.
2) A condenser system.
3) A movable stage. Stage should be controlled by coaxial handle rather than a manual push-pull.
4) 10X and 40X objectives.
5) 10X eyepiece.

Auxiliary equipment should include:

6) Light blue filter (daylight type)
7) Slides
8) Coverslips
9) Several small dropping pipettes
10) Storage box
11) Dust cover.

Relatively low cost microscope is suitable.

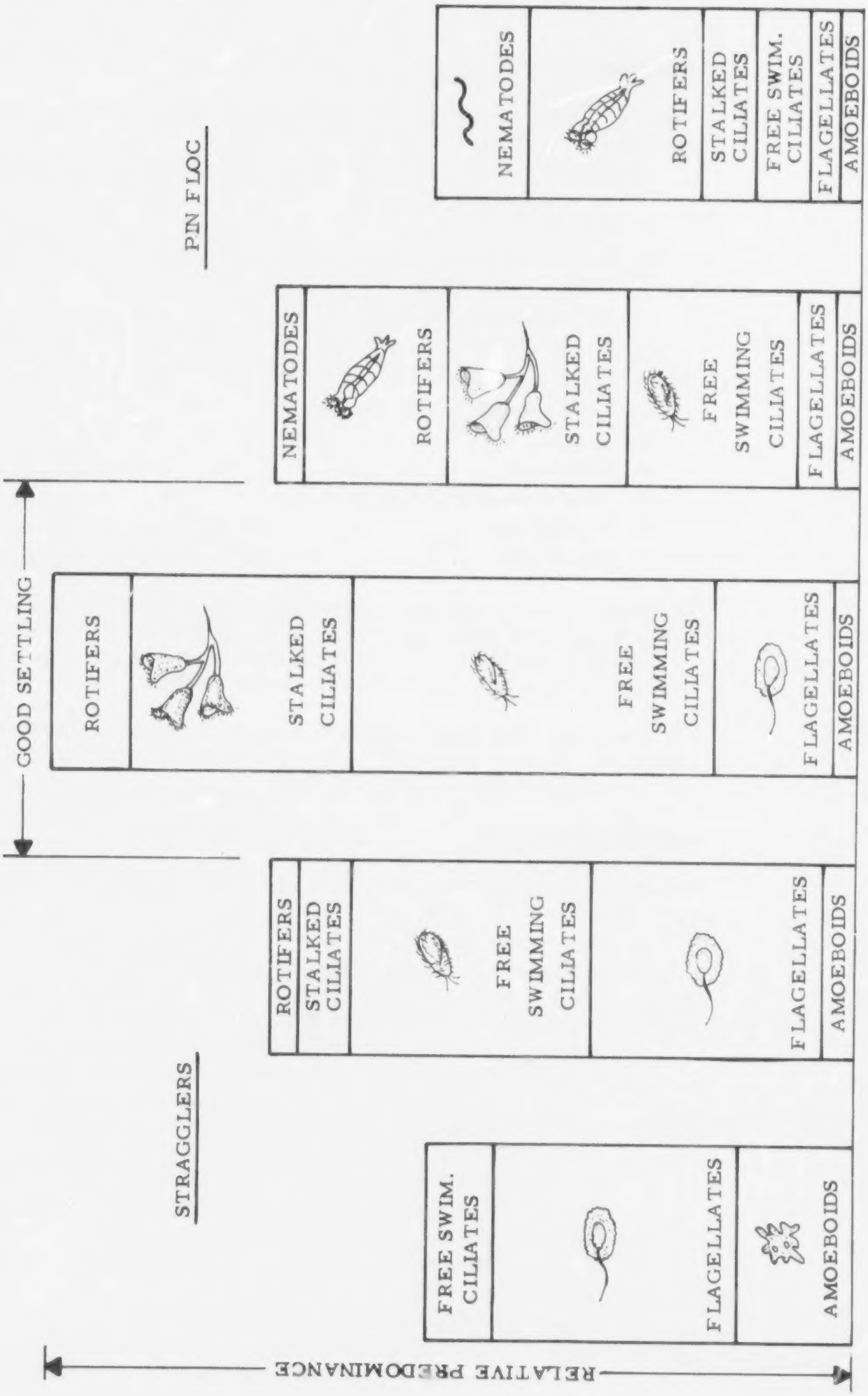
The cost of a microscope can vary between $150.00 and $2,500.00, depending upon the individual's requirements in the way of illumination, lenses and auxiliary equipment. A relatively inexpensive instrument is all that is required for the examination of activated sludge.

*Adapted from "Activated Sludge Process Analyses and Interpretation Workshop Manual," Ministry of the Environment, Toronto, Ontario. (Additional information is also included.)

Use of the Microscope

Procedures for preparing slides and using the microscope should include the following:

1) Clean cover slip and slide.
2) Use pipette to pick up sludge. Put finger on top of pipette until the immersed end of a widetip pipette reaches the bottom of sludge sample. Release your finger to allow sludge into the pipette. Replace your finger on top of pipette and remove the pipette from the sampler beaker. A long tipped eye dropper may also be used.
3) Allow one drop of sludge from the pipette to drop in the middle of the clear area of the glass slide by lifting your finger from top of pipette momentarily, and then replacing your finger.
4) Pick up cover slip by two corners. Do not touch the cleaned area.
5) Pull cover slip along glass slide towards drop of sludge.
6) As soon as cover slip touches drop of sludge, allow cover slip to fall onto glass slide.
7) Pick up glass slide. Place on microscope stage.
8) Move stage up to within approximately 1/8 inch of objective. Look at glass slide through the eyepiece of the microscope.


STRAGGLERS
GOOD SETTLING
PIN FLOC
RELATIVE PREDOMINANCE
FREE SWIM. CILIATES
FLAGELLATES
AMOEBOIDS
ROTIFERS
STALKED CILIATES
FREE SWIMMING CILIATES
FLAGELLATES
AMOEBOIDS
ROTIFERS
STALKED CILIATES
FREE SWIMMING CILIATES
FLAGELLATES
AMOEBOIDS
NEMATODES
ROTIFERS
STALKED CILIATES
FREE SWIMMING CILIATES
FLAGELLATES
AMOEBOIDS
NEMATODES
ROTIFERS
STALKED CILIATES
FREE SWIM. CILIATES
FLAGELLATES
AMOEBOIDS

RELATIVE NUMBER OF MICROORGANISMS VS. SLUDGE QUALITY

FIGURE IV-7

9) Use the coarse adjustment on the microscope to bring the sludge into the field of focus.
10) Use fine adjustment to refine focus to suit your eyes.
11) Identify organisms in the sludge.

Procedures for Examination

When performing a microscopic examination of activated sludge, a sheet of paper should be kept handy to sketch the types observed. In the event that unknown varieties of microorganisms are made, the operator may identify these later. The objective of the examination is to determine relative predominance of microorganisms. This may be accomplished by the procedures outlined below and utilizing a worksheet as illustrated in Figure IV-8.

Examination Procedures:

1) Record the date, time, temperature, and location of the sample on the worksheet.
2) A minimum of three slides per sample should be examined.
3) Scan each slide and count the number of microorganisms in each group.
4) Provide a mark for each microorganism counted in the appropriate group space on the worksheet.
5) After completing the examination of the three slides, total the number of organisms counted in each group.
6) The three higher totals are interpreted as the predominating organisms.

Microscopic examinations of the activated sludge should be made three times per week during peak flow periods. If a consistent trend of predominating organisms is established during normal operating conditions, the frequency of examinations should be decreased to one time per week.

Flow

Accurate flow measurements are essential.

Flow measurements are very important.

A physical measurement of the in-plant flows is essential for true process control. Without these flow measurements, it is impossible to compute hydraulic and organic loadings, F/M ratios, air requirements, detention periods, recycle flows, clarifier underflows, or sludge wasting rates. Without the above parameters to regulate the treatment processes, the operator is left with only a "seat of the pants" approach to process control. Without a measurement of in-plant flows, it is impossible to competently evaluate the operation of the individual treatment units. The measurement of the plant flows also provides a basis for computing costs for billing, estimating chemical needs, predicting the future need for plant expansion or modification, and evaluating the effect of the plant effluent on the receiving stream. Reference to Figure IV-2 will indicate locations of typical in-plant flows that should be measured for process control.

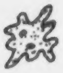
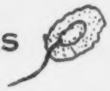
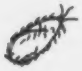
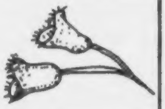
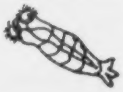
FIGURE IV-8

WORKSHEET FOR MICROSCOPIC EXAMINATION OF ACTIVATED SLUDGE

DATE: ______________________ TIME: __________ AM PM

BY: ______________________ TEMP: __________ °C

SAMPLE LOCATION: ____

MICROORGANISM GROUP	SLIDE NO. 1	SLIDE NO. 2	SLIDE NO. 3	TOTAL
AMOEBOIDS 				
FLAGELLATES 				
FREE SWIMMING CILIATES 				
STALKED CILIATES 				
ROTIFERS 				
WORMS				

RELATIVE PREDOMINANCE:

1. ______________________________
2. ______________________________
3. ______________________________

How to measure flow without a flow meter.

In many of the smaller plants, only the plant influent flow and possibly the plant effluent flow are metered. In these cases, the operator will have to measure the in-plant flows by other means. For instance, a pumped flow may be estimated by multiplying the pump capacity (gpm) times the minutes of pumping time per day.

$$\text{gpd} = (\text{gpm})(\text{min/day})$$

Often, pump capacity may be estimated by measuring the volume of liquid pumped from or to a structure in a timed period. No unmetered flows into or out of the structure must be permitted during the test period. Metered flows into or out of a structure during the test must be taken into account when computing the volume of liquid pumped.

$$\text{gpm} = \frac{(\text{Area, sq. ft.})(\text{Depth, ft.})(7.48\ \text{gal/cu. ft.})}{\text{minutes}} = \text{metered flow, gpm}$$

The metering instrumentation must be properly maintained and calibrated on a regular and routine basis to insure that their measurements are accurate and usable in process control and performance evaluation.

Sludge Blanket Measurement

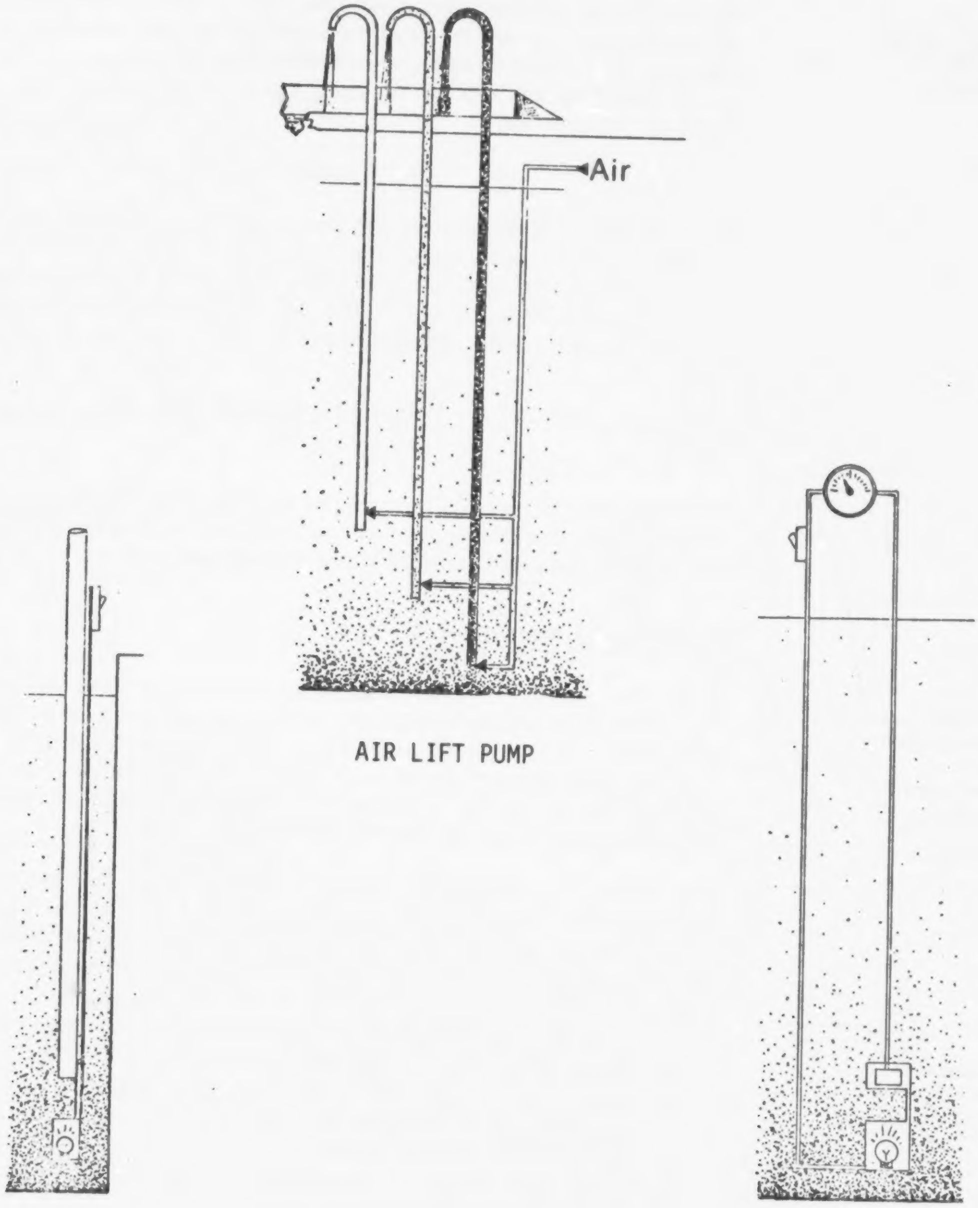
The level of the sludge blanket can be measured with optical or electronic equipment.

Within the secondary clarifier, a separation of the liquid and solids takes place. The solids settle to the bottom of the clarifier while the settled liquid is displaced over the clarifier effluent weirs. If the settled solids are not removed from the tank at a rate equal to or greater than solids input by the aeration effluent flow, a blanket of sludge will accumulate until eventually the solids are washed out in the clarifier effluent flow.

The location of the sludge blanket in relation to the clarifier depth may be determined by various types of devices. Some are commercially available while others must be improvised by the operator. Figure IV-9 shows several variations of sludge blanket finders. The following are some of the different types of blanket finders:

Types of blanket finders.

1) A series of air lift pumps mounted within the clarifier at various depths.
2) Gravity flow tubes located at various depths.
3) Electronic sludge level detector—a light source and photo-electric cell attached to a graduated handle or drop cord. The photo-electric cell actuates a meter, buzzer, light, etc.
4) Sight glass finder—a graduated pipe with a sight glass and light source attached at the lower end.
5) Plexiglass core sampler.
6) Some type of portable pumping unit with a graduated suction pipe or hose.



AIR LIFT PUMP

SIGHT GLASS

ELECTRONIC

SLUDGE BLANKET INDICATORS
FIGURE IV-9

Use the sludge blanket thickness to contorl RAS flow.

Determining the sludge blanket depth in the secondary clarifier in conjunction with other measurements such as the influent flow, MLSS, SVI, and the RAS flow and suspended solids concentration provides valuable information that can be used to control the RAS flow rates. Additionally, this test can be used to evaluate the operation of multiple units, for instance the sludge blanket depth in two clarifiers operating in parallel (both receiving flow from same aeration basin) having equal RAS flow rates should be comparable. If the sludge blanket in one clarifier was rising while the blanket in the other clarifier was falling, it could be concluded that the aeration tank effluent flow is unevenly distributed to the clarifiers. A rising blanket may indicate an inadequate sludge return rate, unbalanced distribution of aeration tank effluent flow, inadequate sludge wasting rates, or a poorly settling sludge. The presence of a poorly settling sludge could be verified with the SVI value. To correct a rising blanket, the operator first determines the reasons by a review of the lab test results, operational logs, and process control parameters. After determining the possible reason for the increased blanket depth, the operator should then take the appropriate corrective measures.

Precautionary Procedures

The following precautionary procedures should be followed in the performance of the sludge blanket measurement:

Run a profile to determine average blanket thickness.

Exercise caution.

1) Select a measuring station located at a point where the blanket depth represents an average of the entire blanket depth. Such a location can be selected by running a profile of the clarifier's entire blanket depth. Thereafter, the selected location should always be used.
2) The sludge blanket finding devices must be used with care. The electronic devices must be lowered slowly until the blanket is located.
3) Procedures and techniques must be uniform for all operations and for all measurements.

Centrifuge Test

Quick method to determine SS.

The centrifuge test provides a quick and convenient method of roughly determining the suspended matter (SS) concentrations of the mixed liquor and return sludge. The centrifuge test results can be used to calculate a mass (solids) balance and to develop various graphs for control and monitoring of the return sludge flow rates, adjustment of the sludge wasting rates, clarifier and aeration sludge detention times, and solids distribution ratios. How to use the centrifuge test results for controlling the activated sludge process is discussed futher in Section 2.04, "SLUDGE QUALITY CONTROL."

Test results vary often.

Due to changing sludge settling and compaction characteristics, the results of the centrifuge test will often vary for similar suspended matter concentrations. The sludge characteristics as reflected by the 30-minute settling test must be considered when interpreting or using the results of the centrifuge test.

Precautionary Procedures

A generalized procedure is described below:

1) Collect a representative sample.
2) Thoroughly mix sample and fill each centrifuge tube exactly to the full mark. The sample must be thoroughly mixed before each pouring. It is recommended that no less than three tubes be run on each sample.
3) Centrifuge samples for 15 minutes with the speed adjustment set at full speed. It is of utmost importance that the samples are centrifuged for the same speed setting each time to promote consistent compaction and meaningful test results.
4) Remove one tube at a time and read the amount of suspended matter concentrated in the bottom of the tube. The results should be recorded for future reference.
5) Use the results of the centrifuge test directly for control and monitoring of the activated sludge process as described in Section 2.04, "SLUDGE QUALITY CONTROL" or convert to suspended matter concentration as described below.

Suspended Matter Correlation

Comparisons of centrifuge and SS tests must be made.

Plot SS and centrifuge test results on graph to obtain relationship.

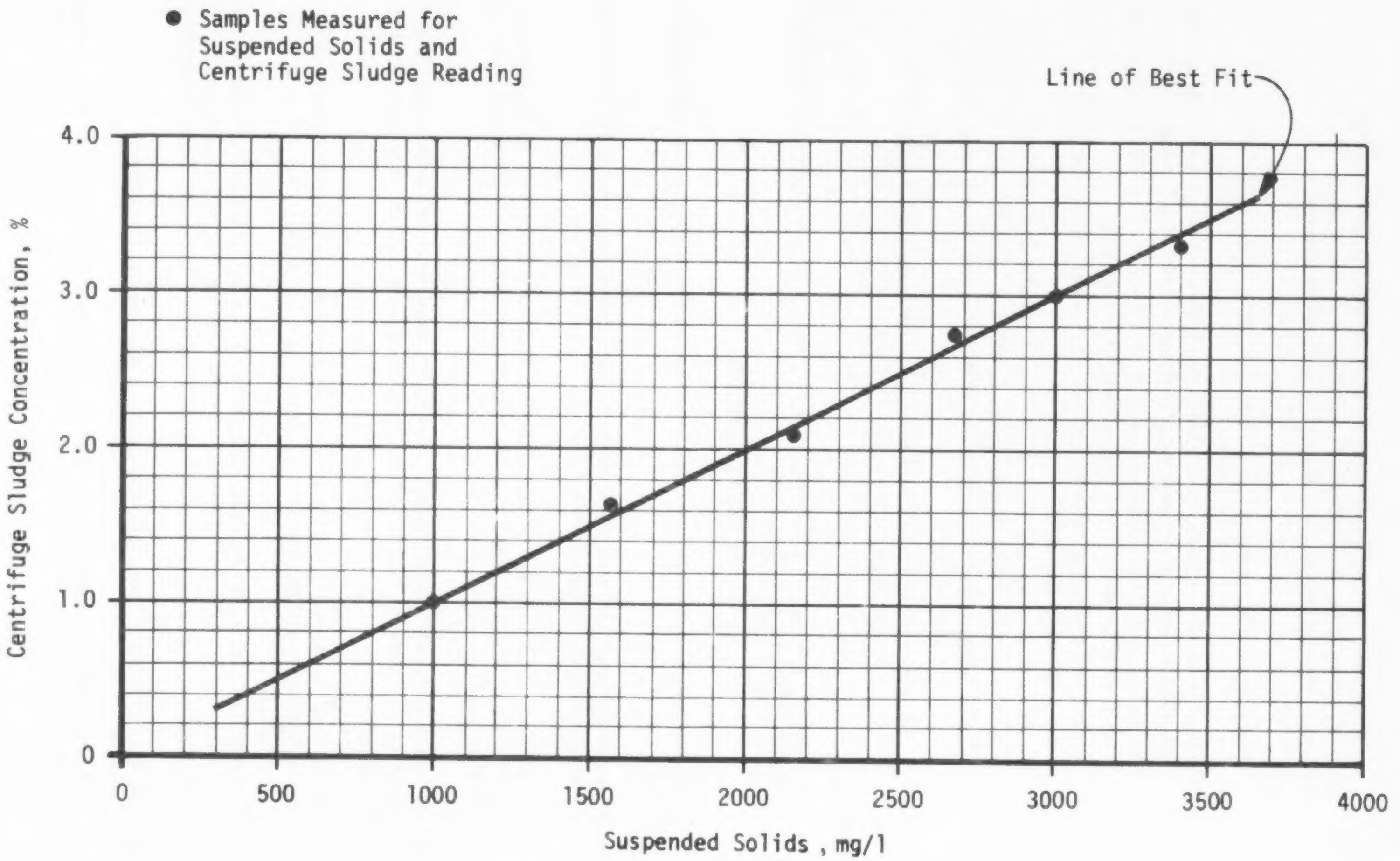
A correlation between the centrifuge test results and the actual filtered suspended matter concentration may be made on a daily basis by performing a centrifuge test and a suspended matter test on the *same* sample of mixed liquor. A 5-day moving average of the spin ratio (SS concentration mg/l/centrifuge sludge concentration, %) should be used to minimize the effect of any variation in this relationship. Another method sometimes used to correlate the results of the two tests is to plot the SS concentration/centrifuge sludge concentration relationship on a graph. After the various points are plotted on the graph, a line of best fit is drawn as shown on Figure IV-10. Since this relationship varies as sludge characteristics change, the line of best fit must be periodically checked and corrected by comparing the graph readout with the results of an actual filtered suspended matter test.

Turbidity

Turbidity refers to the interference of light passage through water. Fine particles of suspended matter hinder the passage of light by scattering and absorbing the rays. Turbidity in the secondary effluent is chiefly due to biological floc that has carried over in the clarifier effluent.

Turbidity checks operational performance.

The turbidity measurement of the secondary effluent is a quick and easy method of checking the operation and performance of the activated sludge process. In recent years, some turbidity analyzers have been permanently installed at the secondary clarifier to continuously measure and indicate the clarity of the secondary effluent. A properly operated activated sludge process generally produces an effluent with a turbidity between 1.0 and 3.0 JTU (Jackson Turbidity Unit). An increasing effluent turbidity indicates an unfavorable trend in process operation which should be promptly investigated and corrected.



CORRELATION OF CENTRIFUGE AND SUSPENDED SOLIDS CONCENTRATIONS

FIGURE IV-10

Recommended way of expressing turbidity.

A photo-electric turbidimeter with an automatic readout in either Jackson Turbidity Units (JTU) or Formazin Turbidity Units (FTU)* is the recommended method of measuring the turbidity of the secondary effluent.

Precautionary Procedures

When performing the turbidity test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) Hold the turbidimeter test vial near the top. The test vial must be kept clean, both on the inside and the outside.
2) Calibrate the turbidimeter using a standard in the range of the turbidity expected.
3) Stir the sample before pouring. Pour the sample slowly into the test vial, being careful not to create or trap air bubbles.
4) Be sure the outside of the test vial is dry before inserting it into the turbidimeter.
5) After allowing any air bubbles to escape, promptly read the results.
6) Replace any test vials that are scratched or damaged.

---

*Jackson Turbidity Units and Formazin Turbidity Units, although not identical, are almost the same for practical purposes.

REFERENCES

APHA, AWWA, WPCF, *Standard Methods for Examination of Water and Wastewater*, 14th Edition, 1976.

California Water Pollution control Association, *Laboratory Procedures for Operators of Water Pollution Control Plants*, 1970.

Kerri, Kenneth D., et al., *A field Study Training Program, Operation of Wastewater Treatment Plants*, (Chapters 6 and 14), Sacramento State College Department of Civil Engineering.

Ministry of the Enviornment - *Activated Sludge Process Anaylses and Interpretation Workshop Manual*, Training, Certification, and Safety Section, Toronto, Ontario, M4V LP5.

New York State Department of Health - *Laboratory Procedures for Waste-Water Treatment Plant Operators*, Health Education Service, Albany, N.Y.

U.S. Environmental Protection Agency, Technology Transfer - *Handbook for Analytical Quality Control in Water and Wastewater Laboratories*, Analytical Quality Control Laboratory, National Environmental Research Center, Cincinnati, Ohio, June, 1972.

The Texas Water Utilities Association, *Manual of Wastewater Operations*.

Water Pollution Control Federation, *Simplified Laboratory Procedures for Wastewater Examination*, Publication No. 18, 1971.

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1.01 INTRODUCTION

Select the measure with least adverse effect.

Know the process.

This section of the manual presents troubleshooting procedures for solving the common operating problems experienced in the trickling filter process. With each problem, or observation, is included a list of probable causes, procedures to determine the cause, and the suggested corrective measures listed in the order to be considered. You, the operator, must determine and select one or more of the corrective measures that will restore the process to an efficiency level which will produce the best final effluent quality. In order to evaluate the problem and select the best corrective measure, you must be thoroughly familiar with the trickling filter process and how it fits into the overall treatment plant operation. In addition, you must be familiar with the influent wastewater characteristics, plant flow rates and patterns, design and actual loading parameters, performance of the overall plant and individual processes, and current maintenance procedures.

1.02 TROUBLESHOOTING GUIDES

There are five problems that frequently occur in the operation of a trickling filter process. These problems are listed below and are referenced to the troubleshooting guides which are presented on the following pages:

INDEX TO TROUBLESHOOTING GUIDES

Troubleshooting Guide No.	Problem Indicator
1	Filter Flies
2	Odors
3	Ponding
4	High Effluent Suspended Solids
5	Freezing

TRICKLING FILTER PROCESS

TROUBLESHOOTING GUIDE I — Filter Flies

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Filter Flies. a. Gnat-sized moth-like flies. b. Dark brown, worm-like larvae in filter slime growth.	A. Poor distribution of wastewater, especially along the filter wall.	1. Visually check.	1) Unclog spray orifices or nozzles. 2) Provide orifice openings at end of distributor arm to spray walls or open dump gates slightly for a spray effect on filter wall.	pg II-19 pg II-19
	B. Hydraulic loading insufficient to keep fly eggs and larvae washed from filter bed.	1. Calculate hydraulic loading. Hydraulic loadings greater than 200 gpd/sq. ft. are usually required.	1) Prevent completion of the filter fly life cycle in the order of the following remedies: a) Increase recirculation rate. b) Flood Filter for several hours each week during fly season or, c) Chlorinate filter influent for several hours each week maintaining a 1 to 2 mg/l residual at the distributor outlet. d) Spray filter walls and other areas where flies rest with a residual-type insecticide—if not prohibited by State or local regulatory agencies. DO NOT spray surface of media.	pg II-19

TRICKLING FILTER PROCESS

TROUBLESHOOTING GUIDE 2 - ODORS

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Odors (Anaerobic decomposition within the filter.)	A. Excessive organic loading. a. Industrial wastes.	1. Calculate organic loading. a. Check industries for unusual waste discharge.	1) Utilize a commercial masking agent *while* making the appropriate corrections.	pg II-15 & II-20
			2) Encourage aerobic conditions in pre-treatment units—try pre-chlorination, aeration, or recirculation during low night flows.	pg II-20
			3) Enforce industrial waste ordinance.	
			4) Improve operation of primary sedimentation tanks.	
			5) Increase recirculation rate to dilute organic strength and improve oxygen transfer.	pg II-9
			6) Chlorinate filter influent for for several hours each day during low flow maintaining a 1 to 2 mg/l residual at distributor outlet.	pg II-20
			7) If design loading is being exceeded, plant expansion may be required.	pg II-15 & II-7

TRICKLING FILTER PROCESS

TROUBLESHOOTING GUIDE 2 - ODORS (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
	B. Poor Ventilation.	1. If provided see that vent pipes are clear in filter.	1) Unclog vent pipes.	pg III-10
		2. Check underdrain system is not obstructed or flowing more than half full.	2) Remove all debris from filter effluent channel and flush obstructive materials from underdrain.	pg III-9
		3. Check filter media voids are not filled with biological growths.	3) If underdrain system is flowing more than half full, reduce filter recirculation if possible.	
			4) Improvise a mechanical means of improving ventilation if natural ventilation is inadequate.	pg III-10
			5) Increase circulation to flush out the excess biological growths.	pg II-9
	C. Poor housekeeping.	1. Visually check.	1) Remove all debris from filter media surface.	pg II-2
			2) Wash down distributor splash plates and the side walls above the media.	pg II-2

TRICKLING FILTER PROCESS

TROUBLESHOOTING GUIDE 3 - PONDING

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Ponding of water over filter media.	A. Excessive biological growth in media voids.	1. Check records for increases in organic loading and/or decreases in hydraulic loading or if dosing intervals has been decreased.	1) Loosen surface layer of rock, media.	pg II-21
			2) Flush the area with high pressure stream of water.	pg II-21
			3) Increase recirculation.	pg II-9
			4) Dose the filter influent with Chlorine for 2-4 hours to obtain 1-2 mg/l residual at distributor outlet.	pg II-21
			5) If possible, flood the filter for 24 hours.	pg II-21 & III-9
			6) If possible, shut down TF - dry media and wash out.	pg II-21
	B. Media is nonuniformly sized, disintegrating or too small.	1. Visually inspect.	1) Dry out filter and check media. Replace nonuniformly sized, or damaged media.	p II-21 & III-6
	C. Poor housekeeping.	1. Visually inspect.	1) Remove all leaves, paper, sticks, and other debris accumulating on filter media surface.	pg II-2

TRICKLING FILTER PROCESS

TROUBLESHOOTING GUIDE 4 - HIGH EFFLUENT SUSPENDED SOLIDS

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Increase in Clarifier Effluent Suspended Solids.	A. Excessive sloughing from filter.	1. Check seasonal changes that would affect microorganisms.	1) Wait for season to change or try polymer addition.	pg II-23
		2. Check organic loading. a. Industrial wastes.	1) If there is a high rate of loading, decrease by using more filters, if available.	pg II-15
			2) Enforce industrial waste ordinance.	pg II-23
			3) Increase clarifier underflow rate.	pg II-12
			4) Plant expansion may be necessary.	pg II-12 & II-23
	B. Denitrification in clarifier.	1. Check to see if filter effluent is nitrified and sludge floats in clumps.	1) Increase clarifier underflow rate.	
	C. Final clarifier hydraulically overloaded.	1. Calculate clarifier surface overflow rate. (Should not exceed 1200 gpd/sq. ft. at peak flow.)	1) If due to recirculation, reduce recirculation rate during peak flow periods.	pg II-17, II-7 & II-9
			2) Additional clarifiers may be required.	pg II-17

TRICKLING FILTER PROCESS

TROUBLESHOOTING GUIDE 4 - HIGH EFFLUENT SUSPENDED SOLIDS (continued)

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
	D. Equipment malfunction in final clarifier.	1. Check for broken sludge collection equipment.	1) Replace or repair broken equipment.	pg II-23
		2. Check for broken baffles.	2) Adjust effuent weirs to an equal elevation.	pg II-23 & II-5
		3. Check for uneven flows over effuent weirs.		
	E. Temperature currents in final clarifier.	1. Make temperature survey of the clarifier using a temperature probe on a DO meter.	1) Install baffles to stop short-circuiting.	pg II-23

TRICKLING FILTER PROCESS

TROUBLESHOOTING GUIDE 5 - FREEZING

OBSERVATION	PROBABLE CAUSE	NECESSARY CHECK	REMEDIES	REFERENCES
1. Freezing.	A. Low temperatures.	1. Check atmospheric temperatures.	1) Decrease recirculation.	pg II-9
			2) Operate two-stage fiters in parallel.	pg II-9
			3) Adjust orifices and splash plates for coarse spray.	pg II-24, III-3 & III-6
			4) Construct windbreak.	
			5) If using intermittent dosing, open bleeder valve on the distribution main.	pg III-6
			6) Partially open dump gates at outer end of distributor arms to provide stream along retaining wall instead of a spray.	pg III-6
			7) Cover pump sumps and dosing tanks.	
			8) Manually remove ice formation.	

REFERENCES

Environmental Protection Agency, Technology Transfer, *Process Design Manual for Upgrading Existing Wastewater Treatment Plants*, October, 1974.

Kerri, Kenneth D., et al., *A Field Study Training Program, Operation of Wastewater Treatment Plants*, (Chapter 6), Sacramento State College Department of Civil Engineering.

Lohmeyer, George T., *Trickling Filters and Their Operation*, Water & Sewage Works, September, 1958.

New York State Department of Health, *Manual of Instruction for Sewage Treatment Plant Operations*.

The South Carolina Water and Sewage Works Association, *Correspondence Course Manual for Sewage Plant Operators*, Class C, 1962.

The Texas Water Utilities Association, *Manual of Wastewater Operations*, (Chapter 12), 1971.

Water Pollution Control Federation, *Operation of Wastewater Treatment Plants*, Manual of Practice No. 11, 1970.

2.01 INTRODUCTION

Importance of a properly controlled operation.

The trickling filter process is reliable and can treat shock organic loads. It requires much less monitoring and control then the activated sludge process. However, proper operation and control is still required to achieve peak performance and to avoid operational problems such as ponding, odors, flies, and freezing. Table II-1 presents guidelines to achieving successful process control.

Acceptable ranges are given herein.

The operating parameters given in this section are intended as acceptable ranges to guide the operator in achieving operational control at his plant. Operation and control of a trickling filter process should be based on its response and performance. The success or failure in achieving the best possible performance from the treatment process is dependent on the operator.

TABLE II-1

GUIDE TO SUCCESSFUL PROCESS CONTROL

REQUIREMENT	REFERENCE
1. Sound operational and preventive maintenance measures.	Section 2.02, OPERATIONAL GUIDES
2. Laboratory monitoring	Section 4.02, LABORATORY SAMPLING AND TESTING PROGRAM
3. Accurate, up-to-date records.	Appendix A, OPERATIONAL RECORDS
4. Evaluation of operational and laboratory data.	Section 4.03, LABORATORY CONTROL TESTS
5. Application of data evaluation to adjustment of the process.	Section 2.04, PROCESS CONTROL
6. Troubleshooting problems before they become serious.	Section 1.02, TROUBLESHOOTING GUIDES

2.02 OPERATIONAL GUIDES

Operational guides are provided on the following pages to aid the operator in establishing routine operational procedures for his trickling filter process.

Performance of the routine operational procedures is not complete without a competent preventive maintenance program. Every item of operating equipment requires frequent attention with particular emphasis on lubrication and other preventive maintenance requirements to ensure trouble-free operation and minimum maintenance costs. A good preventive maintenance program helps to improve process control by ensuring that the equipment remains operational.

TRICKLING FILTER PROCESS

OPERATIONAL GUIDE 1 - TRICKLING FILTER

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
A. ROTARY DISTRIBUTOR	1. Check that distributor rotates smoothly.	1a) Visually observe. 1b) Jumpy operation could denote bearing damage and/or malfunction of pumps.	Daily	pg III-3
	2. Clean clogged orifices.	2a) Shut off the flow to the filter. 2b) WAIT for arms to stop rotating before proceeding. 2c) Be CAREFUL when walking on media surface—it is extremely slippery. 2d) Remove obstructive materials from orifices. 2e) Open end dump gates and flush the distributor arms. 2f) Return unit to normal service.	Daily	pg III-3
	3. Hose slime growths off splash plates.	3a) Excess growths can affect uniform spreading action of plates.	Daily	pg III-3
	4. Check oil in bearing assembly for water contamination.	4a) Water contamination denotes a badly worn or defective seal. 4b) A leaky seal should be repaired immediately to avoid bearing damage.		
	5. Maintain bearing assembly and drive unit if so equipped.	5a) Follow manufacturer's instructions. 5b) A competent preventive maintenance program is essential for good operation.		
	6. Adjust guy rods.	6a) Should be adjusted with seasonal temperature changes to keep distributor arms leveled.	Seasonally	pg III-3
	7. Winter operation (Freezing conditions).	7a) See Troubleshooting Guide No. 5.		pg II-24

TRICKLING FILTER PROCESS

OPERATIONAL GUIDE 1 - TRICKLING FILTER (continued)

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
B. FIXED-NOZZLE DISTRIBUTION SYSTEM	1. Clogged nozzles.	1a) Shut off flow to lateral.	Daily	pg III-6
		1b) Be CAREFUL when walking on media surface—it is extremely slippery.		
		1c) Disassemble and clean clogged nozzles.		
		1d) Open valve, or remove nozzle, at end of lateral and flush obstructive materials which may be in the lateral.		
		1e) Return to service.		
	2. Flush all dead ends in the distribution piping.	2a) May not be possible with some systems.	Weekly	
	3. Winter operation (Freezing conditions).	3a) See Troubleshooting Guide No. 5.		
C. DOSING SIPHON	1. Check operation.	1a) Observe a dosing cycle. If it is not working properly, check for a clogged siphon vent or a leak in the piping.	Daily	pg III-6
	2. Clean and lubricate float-actuated counters, etc.	2a) Follow manufacturer's instructions.		
	3. Wash down tank walls.	3a) To prevent odors and unsightly accumulation of grease and slime.	Daily	
	4. Clean tank and inspect piping apparatus.	4a) Replace badly corroded piping.	Bi-annually	
	5. Winter operation (Freezing conditions).	5a) Cover tank to minimize loss of heat.		

TRICKLING FILTER PROCESS

OPERATIONAL GUIDE 1 - TRICKLING FILTER (continued)

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
D. MEDIA	1. Visually check. 2. Remove all debris from filter surface.	1a) Check for any indication of ponding, filter flies, and windblown debris.	Daily	pg II-18
E. UNDERDRAIN	1. Inspect.	1a) When needed, flush out obstructive growths and debris. 1b) Remove any obstructive materials in effluent channel. 1c) Underdrain conduits and effluent channel should not be flowing more than half full.	Daily	pg III-9 & III-10
F. WALLS	1. Wash down side walls above media.		Daily	
G. HYDRAULIC LOADING ON FILTER	1. Control recirculation rates for optimum performance.	1a) Review records to determine the lowest recirculation ratio yielding good process performance (based on BOD or COD of the final effluent). 1b) The recirculation ratio should be great enough to avoid the problems of ponding, odors, and filter flies.		pg II-7, II-15 & II-16

TRICKLING FILTER PROCESS

OPERATIONAL GUIDE 2 - SECONDARY CLARIFIER

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
A. TANK	1. Inspect for proper operation.	1a) Mechanical equipment.	Twice/shift	pg II-12 & II-23
		1b) Presence of floating sludge—see Troubleshooting Guide No. 4.		
	2. Perform daily wash down.	2a) Hose down the influent channels, tank walls—especially at the water line, effluent weir and launders, effluent channel, and sight sludge box or hopper-if so provided.	Daily	
	3. Maintain sludge collection equipment and drive units.	3a) Follow manufacturer's instructions.		
	4. Inspect baffles and effluent weirs.	4a) Maintain baffles in sound condition.	Daily	pg II-23
		4b) Maintain effluent weirs at an equal elevation.		
	5. Check sludge withdrawal rate and frequency.	5a) Sludge should be removed before it becomes septic and floats to the surface, preferably on a continuous basis.	Twice/shift	pg II-12

TRICKLING FILTER PROCESS

OPERATIONAL GUIDE 3 - PUMPING EQUIPMENT AND PIPING

EQUIPMENT	SUGGESTED STEP PROCEDURES	DETAILS	FREQUENCY	REFERENCE
A. PUMPS	1. Check operation of the pumps and motors.	1a) Check for excessive vibration, unusual noises, lubricant leakage, and overheating. 1b) Check oil reservoir level—if so equipped. 1c) Check oil feed rate—if so equipped. 1d) Check packing or mechanical seals—make adjustments per manufacturer's instructions. 1e) Check for proper position of suction and discharge valves.	Twice/shift	
	2. Alternate pumps in service.		Daily	
	3. Maintain pumping units.	3a) Follow manufacturer's instructions.		
	4. Fully open and close all valves.	4a) Make necessary adjustments or repairs. 4b) Maintain valves and operators according to manufacturer's instructions.	Monthly	
	5. Check operation of air vacuum/relief valves, flow meters, ect.	5a) Maintain according to manufacturer's instructions.	Weekly	

2.03 PERFORMANCE EVALUATION

Competent process control includes evaluation of process performance.

Evaluation of process performance is an essential part of competent process control and operation. The evaluation is helpful in determining process response to various modes of operation, developing performance trends, and identifying the causes of operational problems. For trickling filters, performance evaluation consists of reviewing the COD, BOD, suspended solids, and ammonia nitrogen removal efficiencies in relationship to the mode of operation, loading parameters, and plant recirculation flows. The review and application of lab testing results is further discussed in Section IV - "TRICKLING FILTER LABORATORY CONTROL" and "APPENDIX A".

Many factors affect filter performance.

Trickling filter performance is affected by many factors, such as hydraulic and organic loadings, depth and physical characteristics of the media, method of wastewater distribution, ventilation, characteristics of applied wastewater (temperature, pH, toxicants, etc.), and the hydraulic loading upon the subsequent sedimentation unit. An effective means of reviewing your plant performance is to maintain daily charts or graphs reflecting such data against time. The charts presented in Figure II-1 serve as visual aids in identifying the optimum control parameters and make any trends or changes immediately evident. The preparation and use of these trend charts are discussed further in "APPENDIX A"

Conclusions reached during the process evaluation are then applied to the adjustment of the process (selection of recirculation rates and modes of operation) for efficient and economical operation. Whenever possible, only one process adjustment should be made at a time to allow sufficient time between each change for the process to respond and stabilize.

Importance of complete and accurate records.

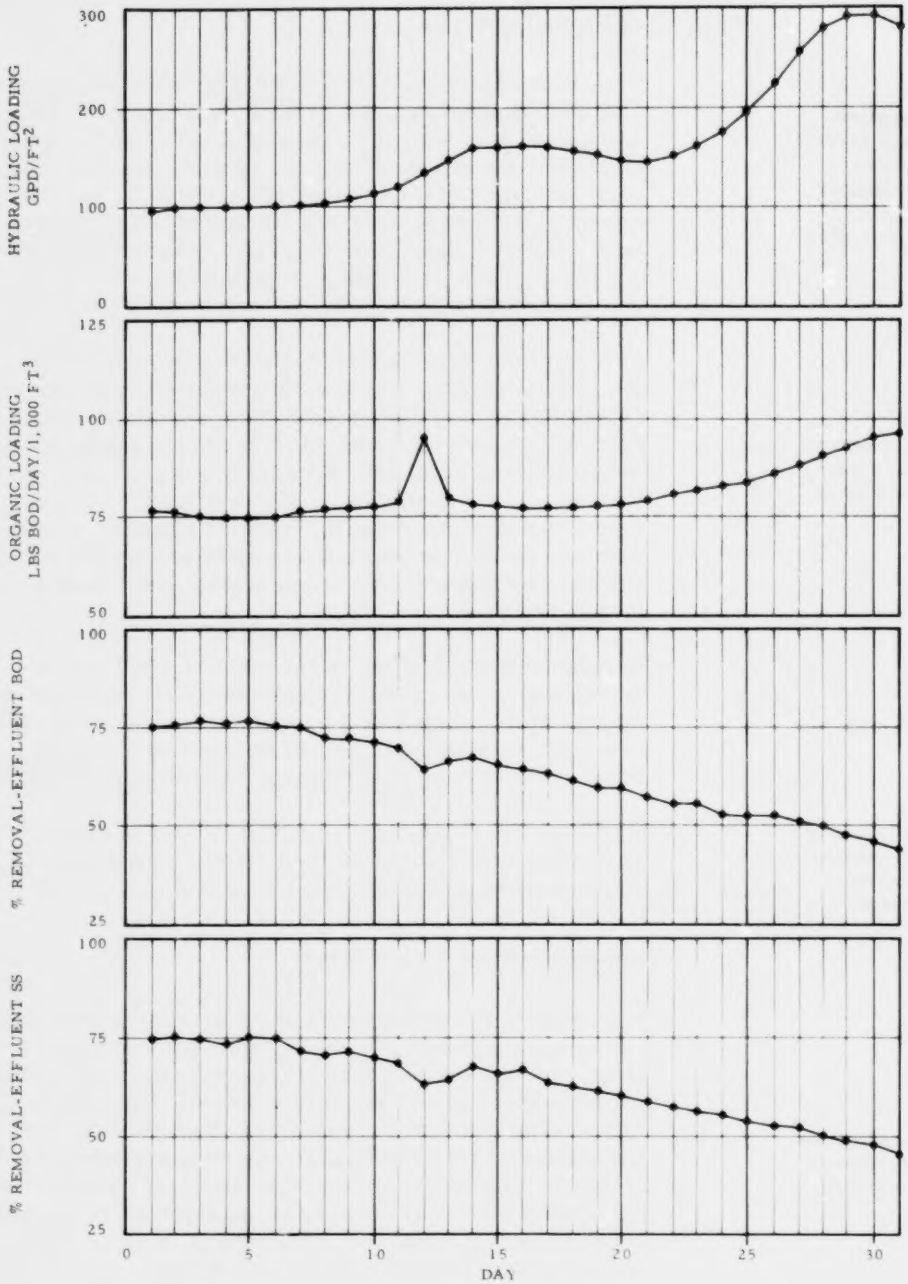
Complete and accurate records of all phases of plant operation and maintenance are essential for accurate performance evaluation and process control. The preparation of operational records is discussed further in "APPENDIX A".

Review of In-Plant Recycled Flow

Recycled flows may cause overloading.

In evaluating the performance of the process or solving problems, a careful consideration should be given to all in-plant recycled flows. Often, in-plant recycled flows are the cause of organic or hydraulic overloading. The sludge processing operations may return decants from digesters, thickeners, centrifuges, or vacuum filters. The waste backwash water from effluent sand filtration processes may also cause hydraulic overloading or other process control problems. The recycled flow from improperly loaded and operated sludge processing units may account for as much as 25 percent of the total plant organic loading. Usually, the majority of recycled flows are returned to the primary sedimentation units where it is hoped organic solids will settle out. In most cases this practice is the major cause of overloading secondary processes due to poor removal of solids in the recycled flows sent to the primary sedimentation units.

The additional loading then results in a greater sludge production, and subsequently an increased loading upon the sludge processing operation. In the trickling filter process, excessive COD or BOD loadings will eventually reduce effluent quality and cause anaerobic conditions to occur in the filter.



HIGH RATE TRICKLING FILTER
(Five-day moving average trend plots)

FIGURE II-1

TYPICAL TRICKLING FILTER TREND PLOTS

Minimize the effect of recycled flows.

Some guidelines that will reduce the effects of recycled flows on the trickling filter process include the following:

1) Add flow continuously or during low night flows to avoid shock loads.
2) Improve efficiency of sludge handling process.
3) Utilize a lagoon or drying bed for poor quality decants from sludge processing operations.
4) Avoid pumping excess water in underflow fed to sludge handling processes.
5) Aerate or pretreat recycled flows to reduce oxygen demands.

2.04 PROCESS CONTROL

Select operating parameters for best performance with least cost.

Operational control of the trickling filter process primarily consists of reviewing operating logs and lab test results to select the proper operational parameters (recirculation rates, hydraulic loading) and modes that yield the required performance at the least cost. The plant operator must be cost conscious and concerned with the conservation of power, and the production of effluent that will meet discharge requirements. For example, to conserve power and minimize operational costs, the operator should select and utilize the lowest recirculation rate that will provide the required performance, but not result in ponding, odors, filter flies, or other problems.

Staging

Staging refers to operating filters in series.

The term staging refers to the operation of trickling filters in series. The purpose of staging is to produce a higher quality effluent by using the first filter in the series as a roughing filter.

Modified concept.

An approach that has been used successfully in England involves alternating the filters, that is, the leading filter is alternated between the two filters operating in series. This practice is referred to as Alternating Double Filtration (A.D.F.). The primary advantage of this approach is that the slime thickness is controlled in both filters by the alternate loading which tends to reduce clogging problems. Unless the filter process is designed to operate with A.D.F., this flexibility in the operational mode is usually non-existent. Basically the mode of staging is dictated by design rather than operational control. As shown in Figure II-2, both filters (stages) are generally constructed the same size with several options for recirculation incorporated into the design. The selection of the recirculation scheme should be based upon process performance. Use the scheme which produces the best effluent.

Recirculation

Why is recirculation used?

Recirculation is practiced in all high-rate trickling filter plants and to some degree in low-rate trickling filter plants. Recirculation is utilized in high-rate trickling filter plants basically to maintain a constant hydraulic loading to prevent clogging the voids in the filter media. In the low-rate trickling filter plant, recirculation may be utilized to maintain a sufficient dosing rate during low flows. Various recirculation arrangements are shown on Figure II-2.

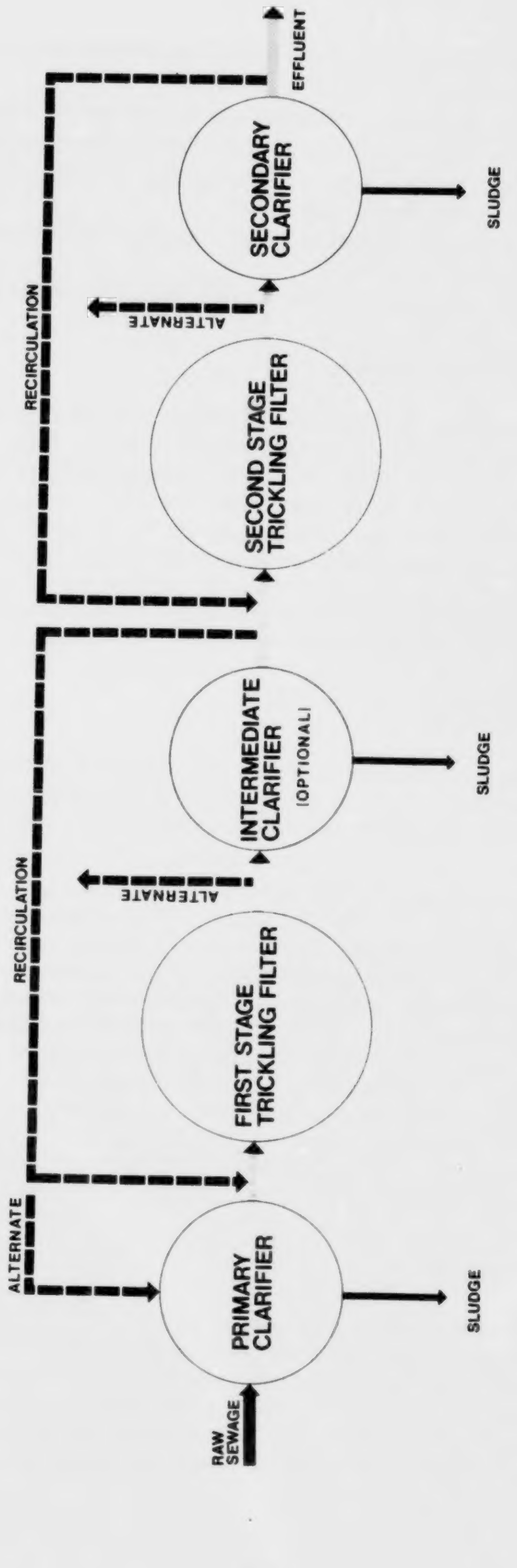

RAW SEWAGE
PRIMARY CLARIFIER
SLUDGE
ALTERNATE
RECIRCULATION
FIRST STAGE TRICKLING FILTER
ALTERNATE
INTERMEDIATE CLARIFIER (OPTIONAL)
SLUDGE
RECIRCULATION
SECOND STAGE TRICKLING FILTER
ALTERNATE
SECONDARY CLARIFIER
SLUDGE
EFFLUENT

FIGURE II – 2

STAGING OF FILTERS

Consider hydraulic loadings.

When selecting the recirculation flow scheme and rate, the hydraulic loading on the filter and affected clarifiers must be considered as well as the hydraulic limitations of the distribution and underdrain systems. As a rule of thumb, the underdrain conduits and effluent channels should not flow more than one-half full.

Usually, the recirculation ratio has a greater effect on filter performance than the recirculation flow scheme. Recirculation ratios may be defined as parts of recirculated flow per part of raw wastewater flow. Therefore, a ratio of 0.5 is equivalent to one half gallon of recirculated flow for each gallon of wastewater to be treated. Although some experimentally based equations have been developed to calculate the amount of recirculation needed, it is recommended that operational control be based on filter response and process performance.

Base control on filter response and performance.

In high-rate trickling filters, recirculation ratios (R/Q) usually range from 0.5 to 4.0 with higher ratios considered to be economically unjustifiable. Common engineering practice is to design the high-rate trickling filter process for ratios of 0.5 to 2.0. Trickling filters utilizing synthetic media employ recirculation as a means of maintaining a minimum wetting rate, i.e., a hydraulic loading (gpm/sq ft) which will maintain biological growth throughout the media depth. The recirculation ratio is determined as shown below:

Example Calculation

A. Data Required
   1. Recirculation flow = 0.2 mgd
   2. Raw wastewater flow = 0.4 mgd

B. Determine the recirculation ratio (R/Q).

$$R/Q = \frac{\text{recirculation flow}}{\text{raw wastewater flow}}$$

$$= \frac{0.2 \text{ mgd}}{0.4 \text{ mgd}}$$

$$= 0.5$$

Recirculation can minimize operational problems and improve filter performance.

Recirculation is often utilized to improve filter performance and to minimize operational problems. Some of the advantages of recirculation include the following:

1. Maintains biological growth throughout synthetic media depth.
2. May improve operation of primary and final sedimentation units during low flow periods by reducing septicity.
3. Dilutes high strength or toxic wastes to make them treatable.
4. Minimizes hydraulic and organic loading variations.
5. Improves distribution of the wastewater over the filter surface.
6. Minimizes odors, ponding, and filter fly breeding by increasing hydraulic loading to encourage continuous sloughing and reduce slime thickness.
7. Prevents biological growth from drying out during low flows.

Be aware of possible adverse effects.

Although the advantages of recirculation generally outweigh the disadvantages, recirculation may result in the following adverse effects:

1. Reduces the wastewater temperature and therefore lowers the rate of biological activity. In extremely cold climates, recirculation may increase the potential for ice formation.
2. Recirculation through a sedimentation unit at rates exceeding hydraulic design limits may reduce efficiency.
3. Increases operational costs due to higher pumping rates.
4. If excessive, it may decrease the organic removal efficiency of the process.

Know your system.

The operator should be familiar with all the modes of recirculation available to him at his plant. Some of the common modes of recirculation are shown on Figure II-2. The mode most favorable to your particular operation should be selected. Operating costs should also be considered in the selection of recirculation modes and rates.

Sludge Removal

Trickling filter sludge requires thickening.

Withdraw sludge before it becomes septic.

Increase sludge withdrawal during periods of heavy sloughing.

Underflow (secondary sludge) from the final sedimentation units is often returned to the primary sedimentation units for resettling with the primary sludge. This method is commonly practiced to thicken the secondary sludge and reduce the volume of water pumped to the processing or sludge disposal facilities. The sludge withdrawal from the final sedimentation tank may be intermittent or continuous. Consideration to remove the sludge before it becomes septic in the sedimentation tank should be made. Usually, visual inspection of the sludge characteristics is sufficient to determine if the withdrawal rate should be increased or decreased. Due to periodic sloughing of biological growth from the filter media, the amount of solids settling in the final sedimentation unit will vary. Sludge from a low-rate trickling filter is relatively stable, and periodic removal at 3 to 24 hour intervals, depending upon operational conditions, is usually sufficient. During warm summer weather and periods of heavy sloughing, removal at 3 to 6 hour intervals may be required. Sludge from a high-rate trickling filter has a higher oxygen demand, and therefore, it must be removed from the sedimentation tank within a short time, preferably on a continuous basis.

Sludge removal frequency is important.

Occasionally, sludge is transferred directly to digestion units, and the frequency and rate of pumping must be set to maintain reasonable sludge concentrations without permitting septic conditions to develop. Rising and floating sludge would indicate that the frequency of pumping should be increased, or that the continuous pumping rate should be increased.

Sludge characteristics and production.

Trickling filter sludge is usually a dark brown, humus material with little or no odor when aerobic. Generally, trickling filters treating domestic wastewater produce 500 to 750 pounds of settleable solids per million gallons of wastewater treated. The sludge produced by a low-rate filter usually has a total dry solids content of one to seven percent after settling in the sedimentation tank. The sludge produced by a high-rate filter is lighter and fluffier with a total dry solids content ranging from one-half to three percent.

Simple method to calculate sludge pumping frequency.

There are several methods of estimating the volume of sludge that must be removed from a trickling filter process. The simplest method is based on a settleable solids test (Imhoff Cone Test) of a composite sample* of the filter effluent. The volume of sludge to be removed may be estimated as follows:

Example Calculation

A. Date Required
   1. Filter effluent settleable solids = 4 ml/l
      (Average of a series of grab samples)
   2. Flow to clarifier = 900,000 gpd

B. Determine the volume of sludge in gallons per day.

(a) Sludge vol., gpd

$$= \frac{\text{(Settleable Sol., ml/l) (flow, gpd)}}{\text{1,000 ml/l}}$$

$$= \frac{\text{(4 ml/l) (900,000 gpd)}}{\text{1,000 ml/l}}$$

$$= \text{3600 gpd}$$

OR

(b) Sludge vol., gpd

$$= \frac{\text{Sludge Volume, gpd}}{\text{1,440 min/day}}$$

$$= \frac{\text{3600 gpd}}{\text{1,440 min/day}}$$

$$= \text{2.5 gpm}$$

C. Determine pump control.

(a) Percent time on

$$= \frac{\text{(Sludge Volume, gpd) (100\%)}}{\text{(Pumping Rate, gpm) (1,440 min/day)}}$$

$$= \frac{\text{(3600 gpd)(100 \%)}}{\text{(50 gpm) (1,440 min/day)}}$$

$$= 5\%$$

OR

(b) Minutes per hour

$$= \frac{\text{(Percent Time On) (60 minutes/hr)}}{100\%}$$

$$= \frac{\text{(5\%) (60 minutes/hr)}}{100\%}$$

$$= \text{3 minutes/hr}$$

*Composite sample - Refer to Section 4.02 for discussion.

Alternate method to calculate sludge pumping rate.

A second method of estimating the volume of sludge is based on measurement of the sedimentation unit influent and effluent suspended solids, the percent total dry solids in the sludge, and the flow to the clarifier. The volume of sludge to be removed may be estimated as follows:

Example Calculation

A. Data Required
  1. Filter effluent suspended solids = 90 mg/l (composite sample)
  2. Sedimentation unit effluent = 30 mg/l suspended solids
  3. Flow to sedimentation unit = 0.9 mgd
  4. Desired sludge concentration = 1.5% (Some allowance should be made for the irregularity in the filter sloughings)

B. Determine the suspended solids removed by the sedimentation unit in mg/l.

$$\text{SS removed, mg/l} = \text{SS}_{\text{infl., mg/l}} - \text{SS}_{\text{effl., mg/l}}$$

$$= 90 - 30$$

$$= 60 \text{ mg/l}$$

C. Determine the volume of sludge in gallons per day.

$$\text{Sludge Vol., gpd} = \frac{(\text{Flow, mgd})(\text{SS removed, mg/l})}{\text{Desired Sludge Conc., \%}}$$

$$= \frac{(0.9 \text{ mgd})(60 \text{ mg/l})(100\%)}{1.5\%}$$

$$= 3600 \text{ gpd}$$

2.05 LOADING PARAMETERS

Trickling filters are designed with loading criteria for operation.

A trickling filter process is designed with loading parameters as criteria for operation. Operation of the process within these parameters is essential if design performance is to be achieved and discharge requirements met on a continuous basis. The process control parameters for trickling filters are generally based on organic loading and hydraulic loading. In considering the trickling filter process, the filter or filters and the following sedimentation unit should always be considered as one unit in both design and operation. The process control parameter for sedimentation units is generally based on the surface overflow rate. Exceeding the design parameters of any unit process will eventually result in a poor quality effluent.

Organic Loading

BOD loading in recirculation flow should be ignored.

The organic loading is commonly expressed as pounds of BOD applied per day per 1,000 cubic feet, cubic yard, or acre-foot of media. Where recirculation is practiced, an additional organic load is contained in the recirculated flow. This added loading is included in the calculations by some operators and omitted by others since it is included in the influent load. The Water Pollution Control Federation *Manual of Practice No. 6., Units of Expression for Waste-Water Treatment,* expresses BOD loading as lb BOD/day/1,000 cu. ft. excluding the additional BOD load contributed by the recirculated flow in the high-rate filter plant. To eliminate confusion in making data comparisons with other plants, it is suggested that the BOD of the recirculated flow be ignored. The BOD loading is determined as follows:

Example Calculation

How to calculate BOD loading for trickling filters.

A. Data Required
   1. Primary effluent BOD = 132 mg/l
   2. Raw wastewater flow = 0.4 mgd
   3. Diameter of filter = 50 ft.
   4. Depth of filter media = 3 ft.

B. Determine pounds of BOD applied per day.

BOD Applied lbs/day = (BOD, mg/l) (Flow, mgd) (8.34 lbs/gal)

= (132 mg/l) (0.4 mgd) (8.34 lbs/gal)

= 440

C. Determine the filter surface area in square feet.

Surface Area, sq. feet = (0.785) (Dia., ft.) (Dia., ft.)*

= (0.785) (50 ft.) (50 ft.)

= 1963.5

*Surface Area = × Dia. × Dia. = (0.785) (dia.) (dia.) or 0.785 $(\text{Dia})^2$

D. Determine the volume of filter media in 1000 cubic feet.

$$\text{Vol. of Media, 1000 cu. ft.} = \frac{(\text{Surface Area, sq. ft.})(\text{Depth, ft.})}{1000 \text{ units}}$$

$$= \frac{(1962.5 \text{ sq. ft.})(3 \text{ ft.})}{1000 \text{ units}}$$

= 5.88 or 5.9 thousand cubic feet

E. Determine the BOD loading.

$$\text{BOD Loading, lbs BOD/day/ 1000 cu. ft.} = \frac{\text{BOD applied, lbs/day}}{\text{Volume of Media, 1000 cu. ft.}}$$

$$= \frac{\text{440, lbs/day}}{\text{5.9 thousand cu. ft.}}$$

$$= 75$$

Hydraulic Loading

Hydraulic loading can be limited by filter distribution and underdrain systems.

The WPCF *Manual of Practice No. 6* expresses hydraulic loading as gallons waste flow (including recirculation) per day per square foot of surface area (gpd/sq. ft.). Often, the hydraulic loading of a trickling filter is limited by the hydraulic capacity of either the distribution or underdrain systems. The hydraulic loading on the super-rate trickling filters (synthetic media-filled towers) is commonly expressed as gallons per minute per square foot of surface area (gpm/sq. ft.). The hydraulic loading may be determined as follows:

How to calculate hydraulic loading for trickling filters.

Example Calculation

A. Data Required
  1. Raw wastewater flow = 0.4 mgd = 400,000 gpd
  2. Recirculation flow = 0.2 mgd = 200,000 gpd
  3. Diameter of filter = 50 ft.

B. Determine the total flow applied to the filter in gallons per day.

$$\text{Total Flow, gpd} = \text{Raw Wastewater Flow, gpd} + \text{Recirc. Flow, gpd}$$

$$= 400{,}000 + 200{,}000$$

$$= 600{,}000$$

C. Determine the surface area of the filter in square feet.

$$\text{Surface Area, sq. ft.} = (0.785)\,(\text{Dia., ft.})\,(\text{Dia., ft.})^*$$

$$= (0.785)\,(50)\,(50)$$

$$= 1963.5$$

D. Determine the hydraulic loading.

$$\text{Hydraulic Loading, gpd/sq. ft.} = \frac{\text{Total Flow, gpd}}{\text{Surface Area, sq. ft.}}$$

$$\text{Hydraulic Loading,} = \frac{600{,}000}{1963.5}$$

$$= 306$$

$$^{*}\text{Surface Area} = \frac{3.14}{4}(\text{Dia.})(\text{Dia.}) = 0.785(\text{Dia.})(\text{Dia.}) \text{ or } 0.785(\text{Dia.})^2$$

Surface Overflow Rate

Importance of hydraulic loading on sedimentation units.

The surface overflow rate is the parameter commonly used to measure the hydraulic loading on the sedimentation units. The surface overflow rate is expressed as gallons waste flow per day per square foot of surface area (gpd/sq. ft.). The surface overflow rate is directly related to the sedimentation unit's ability to effectively remove settleable solids. Normally, if the surface overflow rate is within the design range, it can be assumed that the detention time and weir overflow rates are also within the design range. However, consideration should be given to flow distribution which can cause short circuiting of flow through the unit. Sedimentation units which follow low and high rate trickling filters are commonly designed with maximum surface overflow rates of 1000 gpd/sq. ft. and 800 gpd/sq. ft., respectively.

The surface overlow rate is determined as shown below:

How to calculate surface overflow rate.

Example Calculation

A. Data Required
   1. Peak hour influent wastewater flow = 600,000 gpd
   2. Recirculated flow from sedimentation unit effluent = 300,000 gpd
   3. Diameter of sedimentation unit = 40 ft.

B. Determine the total flow in gallons per day.

Total Flow, gpd = Influent Wastewater Flow, gpd + Recirculated Flow, gpd

= 600,000 + 300,000

= 900,000

C. Determine the surface area of the sedimentation unit in square feet.

$$\text{Surface Area, sq. ft.} = (0.785)(\text{Dia., ft.})(\text{Dia., ft.})^{*}$$
$$= (0.785)(40)(40)$$
$$= 1256$$

D. Determine the surface overflow rate.

$$\text{Surface Overflow Rate, gpd/sq. ft.} = \frac{\text{Flow, gpd}}{\text{Surface Area, sq. ft.}}$$
$$= \frac{900{,}000}{1256}$$
$$= 717$$

$$^{*}\text{Surface Area} = \frac{3.14}{4}(\text{Dia.})(\text{Dia.}) = (0.785)(\text{Dia.})(\text{Dia.}) \text{ or } 0.785\,(\text{Dia.})^2$$

2.06 OPERATIONAL PROBLEMS

Common problems with trickling filters.

There are five problems which commonly occur in trickling filter operations:

1) Filter flies
2) Odors
3) Ponding
4) High effluent suspended solids
5) Freezing

Good operational practices minimize problems.

Each of these problems is disucssed in the following sections. Although the trickling filter process does not require complicated or stringent process control measures, it does require daily attention and maintenance for an efficient and trouble-free operation. Some of these practices are listed below:

1) Keep the distributor orifices or spray nozzles free of obstructions.
2) Keep excessive growths hosed off the distributor splash plates and the side walls above the media.
3) Keep the distributor arm system in good repair and leveled to ensure the wastewater is applied uniformly over the filter bed.
4) Keep all obstructive materials removed from the filter surface, the underdrain conduits and effluent channel.
5) Avoid expected problems by implementing preventive measures on a routine basis.
6) Do not allow problems to become serious before correcting.

Filter Flies

Beneficial when in small numbers.

Filter flies may become a serious nuisance during summer months.

The filter fly is a gnat-sized, moth-like fly that often breeds in the slimes of a trickling filter. Its dark brown, worm-like larvae live in the trickling filter slime performing a useful function by consuming the dead and decaying biological slime growths. At the completion of metamorphosis, the larvae emerge from the filter as adult flies and they create a considerable nuisance when present. In addition to being unsanitary, the flies get into the eyes, nose, and ears, and cause a great deal of physical discomfort and irritation. During the cooler part of the year, filter flies usually exist in numbers which do not present problems. But in the warmer summer months, due to their shorter life cycle (7 days or possibly less), the flies emerge from infested filter beds in vast numbers, presenting a serious nuisance. Although the flies are capable of flying only a short distance, they may be carried by the wind over considerable distances to residential areas.

Implement preventive measures.

Prevent completion of the flies life cycle.

For these reasons, preventive measures should be implemented as a routine program to avoid the development of a nuisance problem and subsequent complaints. Unfortunately, the filter fly and its larvae are not easily destroyed. The most effective means of control is to prevent the completion of its life cycle.

Some probable causes for filter fly problems include the following:

1. Poor distribution of influent wastewater, espeically along the filter wall.
2. Hydraulic loading rates are insufficient to keep fly eggs and larvae washed from the filter media.
3. Preventive measures program not being implemented on a routine basis.

Corrective measures for fly problems.

One or more of the following corrective measures may be needed to control fly problems in any given situation. The measures best suited to your particular operation with the least adverse effect on the quality of the plant's final effluent should be selected. The measures are listed in the suggested order of consideration.

Proper maintenance is important.

Possible solution when the recirculation rate can not be reduced.

Can the hydraulic loading be increased by recirculation?

Possible control measure if filter design permits flooding.

- The distribution system should be properly maintained so that wastewater is uniformly applied over the media. Keep distributor orifices or spray nozzles free of all obstructions. Keep the biological growths adhering to the splash plates hosed off. If distributor arms are not equipped with spray nozzles at the outer end to keep the media adjacent to the wall and the inside surface of the wall wet, either tap the ends of the distributor arm or open dump gates slightly for a spray effect.
- Slow down the distributor arm rotation by reversing some of the spray nozzle directions. This will act to brake the rotating arm.
- Increase the recirculation rate to help wash fly larvae from the filter bed. Hydraulic loadings in excess of 200 gpd/sq. ft. will often minimize filter fly problems.
- On a routine weekly basis, flood the filter for several hours to prevent completion of the filter fly life cycle. When this measure is used, consideration should be given to the resultant hydraulic loading placed on the filters remaining in service. Care should be exercised in releasing the wastewater from the flooded filter such that the hydraulic design capacity of the secondary sedimentation units is not exceeded, resulting in the washout of settleable solids.

Unwise use of chlorine may lower effluent quality.

- On a routine weekly basis, preferably during a period of low flow, dose the filter influent for several hours (no more than 8 hours at a time) with sufficient chlorine to maintain a 1 to 2 mg/l residual at the distributor outlet. The application of chorine will cause sloughing of the upper layer of media slime where fly larvae and pupae reside. Caution should be exercised during prolonged chlorine application at higher residuals. This could cause too much of the slime layer to slough off and reduce filter performance.

First check with State and local regulatory agencies.

- If not prohibited by State of local regulatory agencies, spray filter walls and other areas where the flies rest with a residual-type insecticide. Do not spray insecticide onto the filter media, as the insecticide may harm the slime growth and contaminate the receiving waters. Insecticide treatment should be repeated at intervals of two or four weeks. Alternate the type of insecticide used to avoid developing a resistant strain of the fly.

Odors

Causes for odors.

Indication that other operational problems may exist.

Foul odors coming from a filter are generally due to anaerobic conditions occurring within the slime growth of the filter. When the available dissolved oxygen is consumed by the microorganisms, conditions which cause anaerobic decomposition will occur. It is normal for the innermost slime layer next to the media to be anaerobic, because of inhibited diffusion of oxygen through the outer slime layer. However, the outer slime layer must be completely aerobic; and therefore, a continuous and adequate supply of oxygen (dissolved) is necessary for an efficiently operating filter. Foul odors do not commonly occur when aerobic conditions are maintained in the filter. When odors do occur, it is a good indication of inadequate operational and process control procedures.

Some probable causes of odor problems include the following:

1. Excessive organic loading due to the following: an unusually high BOD in the efluent wastewater; an overloaded or poorly operated primary sedimentation unit; overloaded or poorly operated sludge processing operations resulting in an in-plant recycle flow with a high BOD loading; or inadequate dilution by recirculation.
2. Poor ventilation due to the following: a submerged underdrain system; clogged vent pipes (vertical pipes from underdrain around inner circumference of periphery walls); obstructed underdrain channels; natural ventilation is poor; or void spaces between media is filled with excessive gray to black biological growths.
3. Filter is operating at or over its hydraulic and/or organic loading capacity.
4. Poor housekeeping practices. Accumulation of debris on meida surface.

The following measures should be implemented to resolve odor problems:

Improve primary treatment.

- Evaluate the operation of the primary sedimentation tanks for possile means of improving efficiency. An influent baffle may be needed to prevent short-circuiting, or an improvement in the scum baffle may be necessary to prevent the loss of grease particles from the tank.

Maintain good public relations.

- Utilize one of the commercially available masking agents to make odors less noticeable, thereby avoiding complaints. This should *not* be considered as a solution to the operational problem, but only as a means to avoid a public relations problem while the source of the problem is located and appropriate corrections are made.

Maintain aerobic conditions in upstream treatment units.

- Maintain aerobic conditions in the wastewater collection system, and in primary and secondary sedimentation units (prevent septicity). Recirculation of filter effluent, or final effluent, through the primary sedimentation units during low night flows would be helpful in reducing septicity. The same principle can be utilized by recirculating effluent through the secondary sedimentation units.

Good housekeeping.

- Remove all debris (leaves, sticks, paper, etc.) from the surface of the filter media.
- Check to see that vent pipes are clear.
- Remove all debris from filter effluent channel and periodically flush obstructive materials from the underdrain system.

Recirculation rate may need increasing.

- Increase recirculation to the filter to dilute the strength of the applied wastewater, to flush out the excess biological growths, and to improve oxygen transfer. The hydraulic loading applied to the filter should not be so great that the underdrain system is flowing more than one-half full.

Chlorination lessens the problem.

- On a daily basis, dose the filter influent for several hours, preferably during a period of low flow, with sufficient chlorine to maintain a 1 to 2 mg/l residual at the distributor outlet. Prolonged chlorine application at higher residuals may reduce filter performance. Chlorination only lessens the problem until a permanent solution such as plant expansion, improved operation, or a larger recirculation pump can be provided.

Ponding

Conditions in filter which can and will lead to ponding.

Ponding also known as pooling, is the formation of pools of wastewater on the filter surface due to clogging of the void space between the media. The voids may be clogged by excessive biological growths, accumulated debris, non-uniformly sized media, or disintegrated media fragments. Clogging of the media voids will inhibit air and wastewater passage, thereby reducing filter performance and resulting in anaerobic conditions which are responsible for foul odors. The potential for ponding can be minimized by use of a sufficient hydraulic loading (relative to the organic loading) to keep excess biological growths flushed from the media voids on a routine basis, and by removing any debris which may accumulate on the media surface.

Some probable causes of ponding problems include the following:

1. Application of a high-strength waste with inadequate dilution by recirculation.
2. Inadequate hydraulic loading in relation to the organic loading to keep media voids flushed.
3. Non-uniformly sized media where smaller particles fill the void space between larger particles. This inhibits air ventilation and passage of wastewater.
4. Disintegrating media resulting in clogging of the void space.

5. Uniformly-sized media which is too small to provide adequate void space for air and wastewater passage at current loadings.
6. An accumulation of moss, snails, leaves, sticks, or other such materials which clog filter voids.

Corrective measures for filter ponding.

One or more of the following corrective measures may be needed to control ponding depending on the cause and seriousness of the problem. The measures are listed in the suggested order of consideration. The measures best suited to your particular operation with the least adverse effect on the quality of the plant's final effluent should be selected.

Practice good housekeeping.

- Remove all leaves, paper, sticks, and other debris accumulating on the media surface.

Improve condition and prevent recurrence.

- Increase recirculation to reduce influent strength and improve the hydraulic flushing of media voids.

Cure for minor ponding.

- Agitate and flush the affected portion of the filter surface with a high pressure stream of water.
- Loosen the surface layer of rock in the affected area by raking or forking.

Cure for serious ponding when loading does not permit removal of a filter from service.

- Dose the filter influent for 2 to 4 hours (preferably during low flow) with sufficient chlorine to maintain a 1 to 2 mg/l residual at the distributor outlet. Residuals of 20 to 50 mg/l may be needed when ponding is serious and it is necessary to unload the majority of the biological growth. Significant unloading of the slime layer will reduce the treatment efficiency until a biological balance is re-established. If the treatment facility lacks provisions for application of chlorine to the filter influent flow, chlorinated lime (34%) or HTH powder (70%) may be applied to the affected area at a dosage of 8 to 10 pounds of chlorine per 1,000 square feet of filter surface.

When filter design permits flooding and extra filters are available.

- If the construction of the filter permits, flood the filter, keeping the media submerged for about 24 hours. When utilizing this method, consideration should be given to the resultant loading placed on the filter units remaining in service. To prevent surcharging of the secondary sedimentation units, release the wastewater from the flooded filter slowly, preferably during the low night flow period.

Flooding not possible.

- Remove the filter from service allowing the slime growths to dry out. When placed back into service, the loosened growths drop from the media and wash out with the filter effluent. The length of drying required depends on the weather and the thickness of the growths. A few hours of drying may be adequate to slough the excess growths, while for more seriously clogged media, one or more days of drying time may be required. Portions of a filter media may be dried out by closing off individual distributor arm orifices.

Defective media.

- In the event each of the above measures fail to relieve the problem, remove some of the media for cleaning and inspection. If the media is found to be in satisfactory condition and uniformly-sized (3 to 5 inches) it can be *carefully* placed back into the filter. If the media is defective or too small, it must be replaced.

  CAUTION: All filter underdrain systems can be easily damaged by the weight of heavy equipment or careless placement of media.

High Effluent Suspended Solids

Removal of settleable sloughings is the key to good performance.

The efficiency of the trickling filter process is dependent on the removal of filter sloughings in the final sedimentation units. A high suspended solids concentration in the sedimentation unit effluent is usually indicative that a problem exists in this portion of the trickling filter process.

Causes for high effluent suspended solids.

Some probable causes for high effluent suspended solids include the following:

1. The unit is hydraulically overloaded due to excessive flow rates in conjunction with recirculated flow rates, or the flow is unevenly distributed between multiple units.
2. Sludge collection equipment needs adjustment or repair.
3. Baffles or skirts need repair.
4. Effluent weirs not at an equal elevation.
5. Temperature currents.
6. Rate of sludge withdrawal or frequency is inadequate.
7. Heavy sloughing caused by temperature and biological activity. Shock loadings due to toxic wastes or organic and/or hydraulic overloads.

Things to look for when experiencing high effluent solids.

The following measures should be implemented to determine as well as resolve the problem.

- Check for broken welds, bolts, supports, and/or holes in the baffles and make any needed repairs.
- Check that effluent weirs are set at an equal elevation and make any needed adjustments.
- Check that the sludge collection equipment is operating properly. The condition of the sludge scrapers or flights should be checked and the clearance between the floor and scraper adjusted if needed.

Check hydraulic loading.

- The operator should check the hydraulic loading on each clarifier (see Surface Overflow Rate) by either measuring the flow to each clarifier or by estimating the flow balance between multiple units as indicated by the depth of flow over the weirs in each of the clarifiers. Overloading can result from excessive flow or unevenly distributed flow between multiple units.

Check surface overflow rate.

- Compare the calculated surface overflow rate with the design rate. If the current rate exceeds the design rate, the unit is overloaded and efficient operation can be restored if additional sedimentation facilities are provided. The installation of baffles in the existing unit may improve settling.

Perform temperature profile.

- A temperature profile of the sedimentation unit will identify the presence of any temperature currents. The temperature probe on a dissolved oxygen meter is an excellent tool for this procedure. To make the survey, the temperature profile is measured and recorded at the head, one quarter, one half, three quarters and end of a rectangular or square unit, or at the quarter points across a circular unit. At each point, the temperature is measured at the surface and the quarter points down to the bottom of the tank. Be careful that the temperature probe and wires do not get entangled in the sludge collection equipment. If the deeper temperatures are consistently cooler by 1 to 2° or more, temperature currents are present. The settling will be improved if baffles are installed to break up the currents and stop the turbulence.

Check the sludge removal rate.

- If the sludge floats to the sedimentation unit surface in clumps with numerous small bubbles attached, the problem is most likely related to septicity or denitrification. This problem is best resolved by increasing the sludge removal rate to draw the solids out of the unit more rapidly.

Chemical addition may be required temporarily.

- Polymer addition to the sedimentation unit influent flow may improve the capture of suspended solids. The type of polymer and initial dosage should be determined in the lab by jar tests. It has been reported that a 1 to 2 mg/l dosage of cationic polymer has been effective in some circumstances. The polymer dosage should be periodically adjusted on the basis of the most effective solids capture with the least amount of chemical addition. The rate of sludge removal should be increased during periods of chemical addition and heavy sloughing.

Check for industrial discharges which hinder process performance.

- Conditions such as abnormal pH's, temperatures, or toxic chemicals can be best controlled by enforcing strict industrial waste discharge ordinances. Increasing the recirculation rate will help to buffer the effect of shock loads. However, harmful industrial dumps should be stopped or neutralized at their source whenever possible. If possible, a toxic shock load (usually characterized by an abnormally low or high pH) should be diverted to a holding basin and returned to the plant influent at a very low rate to minimize its effect on the biological processes in the treatment plant (digesters as well as trickling filter processes).

Check for shock hydraulic loadings.

- Frequent hydraulic shock loads may justify the addition of flow equalization basins. These basins should be aerated and mixed to prevent septicity and settling of the solids. In some cases, hydraulic shock loads can be buffered by using the influent wet well and adjoining influent pipe for equalization and controlling the influent wastewater pumps to level out the peak flows. The practice of holding wastewater in the influent sewer for more than a brief period must be avoided.

Freezing

Freezing generally limited to climatic conditions.

This problem is limited to those areas of the country that experience freezing weather conditions. Wastewater that is exposed as a thin film or is not in motion is very susceptible to temperature loss and subsequent freezing. To some extent, ice formation can be minimized by appropriate operational procedures.

Conditions which create freezing problems.

Causes of freezing problems include the following:

1. Loss of temperature in the applied wastewater due to recirculation (the filter acts like a cooling tower).
2. Strong prevailing winds which increase heat loss.
3. Wastewater standing in the distribution system which may freeze when intermittent dosing is practiced.
4. A thin film of spray which freezes more readily than a coarse stream of spray.

Things to help reduce freezing problems.

The potential for ice formation can be reduced by the following measures:

- Decrease recirculation as much as possible to reduce cooling effects upon the wastewater.

- Operate two-stage filters in parallel to reduce cooling effects by making fewer passes through the filters.
- Adjust orifices and splash plates for a coarser spray effect.
- Construct a windbreak to protect the filter from prevailing winds and reduce heat losses.
- Where intermittent dosing is practical, open the bleeder valve in the lower end of the distribution main slightly. This will drain the system between doses.
- Partially open the dump gates at the outer end of the distributor arms to provide a stream rather than a spray along the retaining wall.
- Cover open pump sumps and dosing tanks to reduce heat losses.
- Break up and remove ice formations which may obstruct operation.

REFERENCES

Eckenfeder, W.W., *Biological Waste Treatment*, Pergamon Press, New York, 1961.

Hawks, H.A., *The Ecology of Waste Water Treatment*, Pergamon Press Oxford, 1963.

Kerri, Kenneth D., et al., *A Field Study Training Program, Operation of Wastewater Treatment Plants*, (Chapter 6), Sacramento state College Department of Civil Engineering.

Lohmeyer, George T., *Trickling Filters and Their Operation*, Water & Sewage Works, September 1958.

McKinney, Ross E., *Microbiology for Sanitary Engineers*, McGraw-Hill Book Company Inc., 1962.

National Research Council, *Sewage Treatment at Military Installations*, Sewage Works Journal, 18, No. 5, 1946.

The South Carolina Water and Sewage Works Association, *Correspondence Course Manual for Sewage Plant Operators*, Class C, (Chapter 16) 1962.

The Texas Water Utilities Association, *Manual of Wastewater Operations*, (Chapter 12), 1971.

Water Pollution Control Federation, *Operation of Wastewater Treatment Plants*, Manual of Practice No. 11.

Water Pollution Control Federation, *Sewage Treatment Plant Design*, Manual of Practice No. 8, 1959.

Water Pollution Control Federation, *Units of Expression for Wastewater Treatment*, Manual of Practice No. 6, 1976.

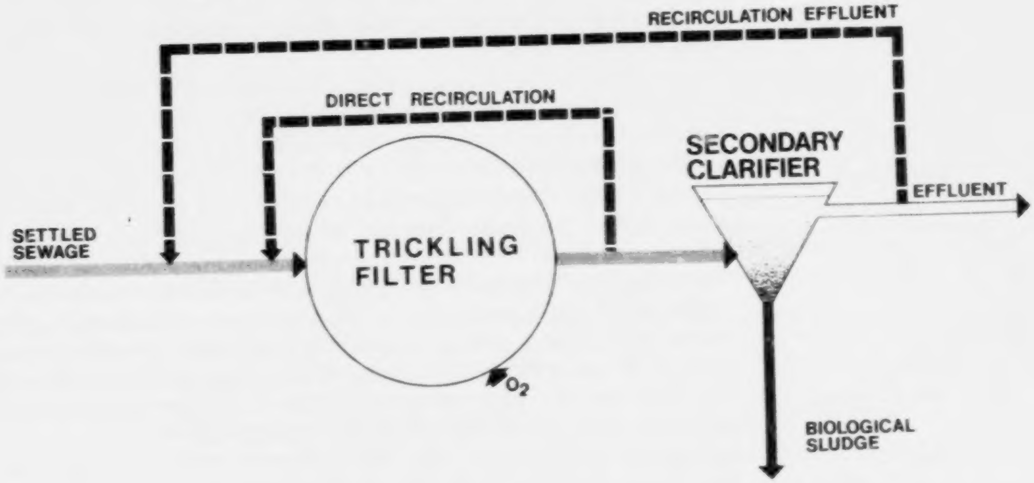
3.01 INTRODUCTION

Why popular.

The trickling filter process was first used in the United States in 1908, and has remained a popular form of wastewater treatment since that time. Inexpensive aeration and process stability are the primary reasons that the trickling filter has remained a popular treatment process. As energy costs increase, the usage of trickling filters as roughing filters is likely to increase.

Trickling filter process.

The trickling filter process consists of a trickling filter and a sedimentation unit. The filter structure is filled with media which provides surface area for the microorganisms to attach themselves. The wastewater is applied at the surface of the trickling filter, and it trickles or splashes over and through the voids of the media where the microorganisms are attached. After the wastewater passes through the filter, it is collected in an underdrain system below the media. Solids which reamin in the wastewater are then settled and removed from the sedimentation unit. A portion of the filter effluent may be recirculated to the head of the filter as shown on Figure III-1.



TYPICAL TRICKLING FILTER PROCESS

FIGURE III-1

Total amount of microorganisms is called the biomass.

The total amount of microorganisms attached to the trickling filter media is called the biomass. The biomass includes algae, bacteria, fungi, protozoa, and higher life forms of organisms such as worms, snails, and insect larvae.

Surface microorganisms are aerobic-Subsurface anaerobic.

Facultative bacteria are the microorganisms responsible for the majority of the treatment which occurs in the trickling filter. The surface microorganisms are aerobic while the microorganisms immediately attached to the media surface or where dissolved oxygen is absent are anaerobic.

Capable of withstanding shock loads.

Because they contain vast numbers and varieties of microorganisms, trickling filters are capable of adapting to changes in environmental conditions and loadings. For this reason shock organic loads have less effect on this process than on some modes of the activated sludge process.

Definitions

Operation of the trickling filter process requires a basic understanding of some key words commonly used by operators. The following provides a framework for understanding what a trickling filter consists of and what makes it function as a treatment unit.

- MEDIA is placed in a structure to provide a surface for the microorganisms to attach themselves. The media frequently consists of rocks, plastic sheeting and redwood laths.
- DISTRIBUTOR ARM is the most common method of evenly applying the wastewater over the media in the structure. The arm is generally propelled by the momentum or force of wastewater being sprayed from orifices located on the arm.
- BIOMASS refers to the total mass of microorganisms attached to the media. In concept, the biomass is similar to the Solids Inventory used in activated sludge terminology to describe the total amount of microorganisms in an activated sludge system.
- RECIRCULATION refers to the pumping of the filter effluent back to the head end of the trickling filter. Recirculation evens out variations in the hydraulic loading.
- SLOUGHING is the process by which the excess growth of the microorganisms falls off of the filter media. When the thickness of the biological growth is too great, the excess microorganisms are washed off of the media and discharged with the filter effluent.
- FILTER UNDERDRAIN consists of a sloped floor under the filter media which allows the wastewater and sloughings to collect in a channel. From the channel the wastewater and sloughings (filter effluent) are transferred to the sedimentation unit for settling and removal.
- HYDRAULIC LOADING refers to the amount of wastewater applied to the surface of the trickling filter media. The hydraulic loading is calculated by dividing the average daily influent flow by the surface area of the filter media. The loading parameter is commonly expressed as gallons per day per square foot of surface area (gpd/sq. ft.).
- ORGANIC LOADING refers to the amount of BOD or COD applied per unit volume of filter media per day. The organic loading is commonly expressed as pounds of BOD applied per day per 1000 cu. ft. (lb BOD/day/1000 cu. ft.).
- LOW RATE TRICKLING FILTERS are operated with an organic loading of 5 to 25 lb BOD applied/day/1000 cu. ft. The low rate filter will frequently produce a nitrified effluent, and low rate filters are becoming slightly more popular because of this capability.
- HIGH RATE TRICKLING FILTERS are operated with organic loadings of 25 to 100 lb BOD applied/day/1000 cu. ft.
- ROUGHING FILTERS are operated at loading rates above 100 lb BOD applied/day/1000 cu. ft. A roughing filter is used to reduce the amount of BOD and/or COD in the wastewater.
- BIOLOGICAL TOWERS refer to the type of trickling filters that are synthetic media-filled, tower-like structures. These towers are sometimes referred to as oxidation or roughing towers. Because of their high hydraulic loading, they are often classified as Super-Rate trickling filters.

- STAGING refers to operating trickling filters in series. Staging is practiced to produce an effluent with a lower BOD and/or COD concentration.

3.02 PROCESS DESCRIPTION

Waste is absorbed by slime growth.

The trickling filter process consists of spraying the wastewater over a bed of media, such as crushed rock, cynders, slate, redwood laths, or molded plastic materials to form a biological slime layer. This slime, or zoogleal film, is composed primarily of bacteria, protozoa, and fungi, and at times includes worms, fly larvae, rotifiers, and snails. Usually sunlight promotes an algal growth on the bed's upper surface. As the wastewater trickles downward through the voids of the media, organic matter and dissolved oxygen are absorbed into the film and at the same time, the metabolic end products such as carbon dioxide, water, nitrates and sulfates are released.

Slime growth sloughs off media.

When the slime layer loses its ability to continue clinging to the media, usually due to either the excess thickness of the slime layer and/or the scouring effect of the wastewater flow, portions of the slime layer slough off into the waste flow. The waste flow containing the metabolic end products and sloughings flows into an underdrain system which supports the media and permits air circulation. The underdrain system has a sloping bottom conveying the waste flow into a main effluent channel.

Sloughings are captured in the clarifier.

In a single stage system, the collected trickling filter effluent is conveyed to a sedimentation unit for the removal of the settleable sloughings. In a multistage system, final sedimentation would follow the last trickling filter stage. In some cases the system may have intermediate sedimentation units between the trickling filter stages.

Principle components of process.

The principal components of the trickling filter process consist of the following:

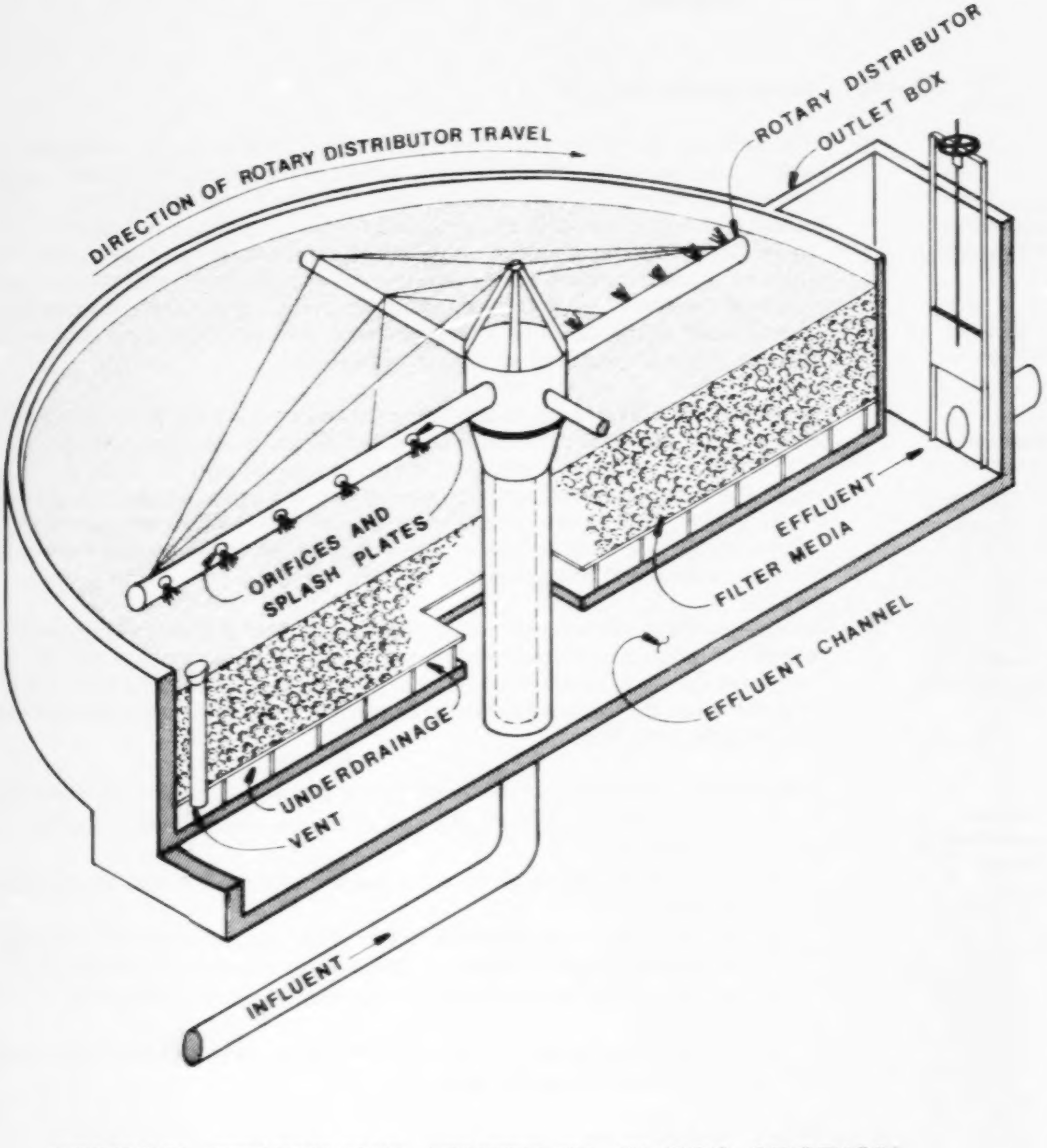
1. The distribution system through which the wastewater is applied to the filter media.
2. The filter media which provides surface area for the microorganisms to grow.
3. The underdrain system which supports the media and provides drainage of the waste flow to a collection channel while permitting air circulation.
4. A final sedimentation tank for the removal of the filter sloughings.

A cross-section of a typical circular trickling filter is shown on Figure III-2 with the principal components identified.

Rotary Distributor

What makes the distribution arm rotate?

The rotary distributor consists of two or more horizontal arms that are mounted on a turntable assembly anchored to a center column, as shown on Figure III-3. The wastewater is uniformly distributed over the media by orifices located in the side of the distributor arms. Usually, the reaction force of the wastewater spray from the orifices provides the force needed to rotate the distributor assembly. In some cases, the distributor assembly is motor driven.


DIRECTION OF ROTARY DISTRIBUTOR TRAVEL
ROTARY DISTRIBUTOR
OUTLET BOX
ORIFICES AND SPLASH PLATES
EFFLUENT
FILTER MEDIA
EFFLUENT CHANNEL
UNDERDRAINAGE
VENT
INFLUENT

TYPICAL TRICKLING FILTER IN CROSS SECTION

FIGURE III - 2

The turntable rests upon and revolves on a ball bearing assembly which operates in an oil bath with a mechanical-type seal between the rotating turntable and the stationary base to eliminate oil leakage and contact with the wastewater.

Maintenance provisions.

The distributor arms are commonly braced by horizontal tie rods. To maintain the distributor arms in the horizontal position and permit seasonal adjustment, the arms are supported vertically by adjustable guy rods from a center mast. A dump gate is provided at the outer end of each arm for flushing the obstructive materials from inside the arm. Often, an orifice is provided in the dump gate to spray the edge of the media to discourage fly breeding. Usually, a drain plug is provided in the center column to facilitate shutdown procedures and prevent damage due to freezing.

Distributor arm rotation speed.

The distributor arms are sized to prevent velocities in excess of 4 feet per second (fps) at maximum flow. Generally, the rotation speed of the reaction driven unit will vary with the flow rate in the range of 0.1 to 2.0 rpm. The four-arm distributors are often equipped with weir boxes at the center column to confine the flow to two arms at minimum flow rates. This feature is provided to maintain proper reaction force for the rotation of the distributor arms from a minimum flow to a maximum flow.

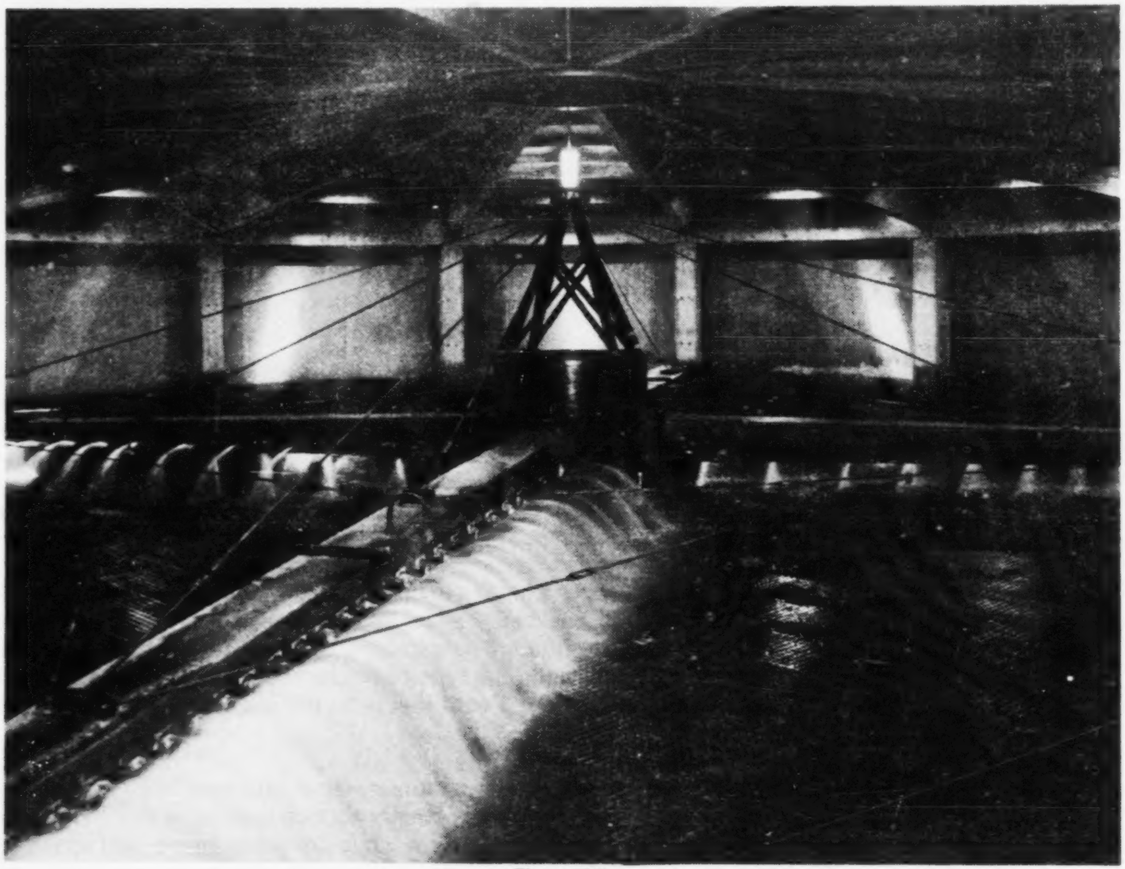


Figure III-3
Rotary Distributor

Fixed Nozzle Distributors

Uncommon in newer plants. Found mostly in older plants.

In the rock-filled filters, fixed-nozzle distribution systems are uncommon and are usually found at older facilities. The distribution system consists of stationary pipes placed in the filter bed with inverted nozzles located at strategic points for a relatively uniform coverage of spraying wastewater over the media. Special nozzles constructed with a deflector for a flat spray pattern are usually used in these filters. Dosing tanks are utilized to provide an intermittent wastewater application. The dosing tanks are usually designed to provide a minimum rest period of 30 sec. at maximum flow. Figure III-4 illustrates the fixed nozzles, a dosing tank and distribution system.

Uniform spray application.

The dosing tanks also provide a varying head so that the spray falls first at a maximum distance from the nozzle and then at a decreasing distance as the head drops. This technique provides a relatively uniform application.

Deep bed filter.

With the introduction of synthetic media, construction of deep-bed, fixed-nozzle filters provide greater contact time and higher wetting rates of wastewater applied. The nozzles are strategically located at points along pipes spraying downward over the bed.

Dosing

Dosing by siphon, pumps or gravity.

The hydraulic head required for operation of the distribution system may be provided by dosing tanks, pumps, or by gravity discharge from the preceding treatment unit.

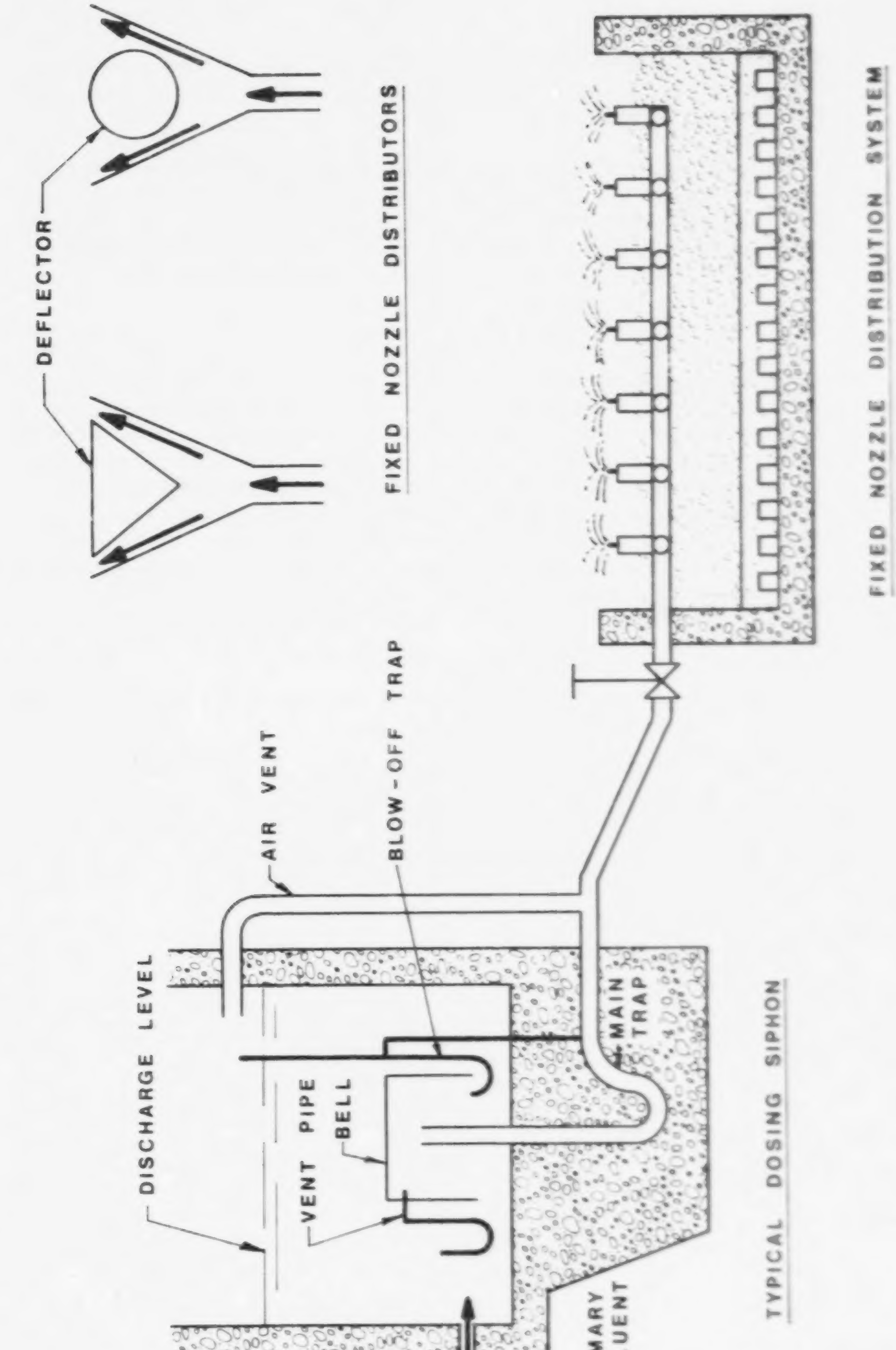
Dosing tanks are usually equipped with an automatic siphon controlling the maximum and minimum head conditions. They also provide an intermittent dosing frequency. A typical dosing siphon is shown in Figure III-4.

Media

Media does not filter wastewater but must be durable, insoluble and uniformly-sized.

The media in a trickling filter does not provide a straining or filtering action as implied by the name, but provides a surface area for the growth of a slime film which is responsible for the removal of organic matter. The media may be crushed rock, slag, coal, bricks, redwood blocks or laths, molded plastic, or any durable, insoluble and uniformly-sized material. Uniformity in media size is required to provide adequate void spaces for air circulation and to avoid flow restriction resulting in a condition known as ponding. The size range of rock media is usually 3 to 5 inches in diameter depending upon the hydraulic loading that the filter has been designed for. High-rate filters use a larger media than the low-rate filters. The durability, cost, and availability are some of the factors that determine the type of media used. The depth of media in rock-filled filters range from 3 to 8 feet with the majority of the biological activity occurring in the upper 3 feet.

In recent years, several forms of manufactured media have been introduced. The manufactured media provides a greater surface area per a specific volume upon which the zoolgeal film may grow while providing ample void space for the free circulation of air. Additional advantages are: a uniform media for better liquid distribution, light-weight material allowing construction of



DEFLECTOR
FIXED NOZZLE DISTRIBUTORS
DISCHARGE LEVEL
VENT PIPE
BELL
BLOW-OFF TRAP
AIR VENT
MAIN TRAP
PRIMARY EFFLUENT
TYPICAL DOSING SIPHON
FIXED NOZZLE DISTRIBUTION SYSTEM

FIXED-NOZZLE DISTRIBUTION SYSTEM

FIGURE III-4

Advantages of synthetic media.

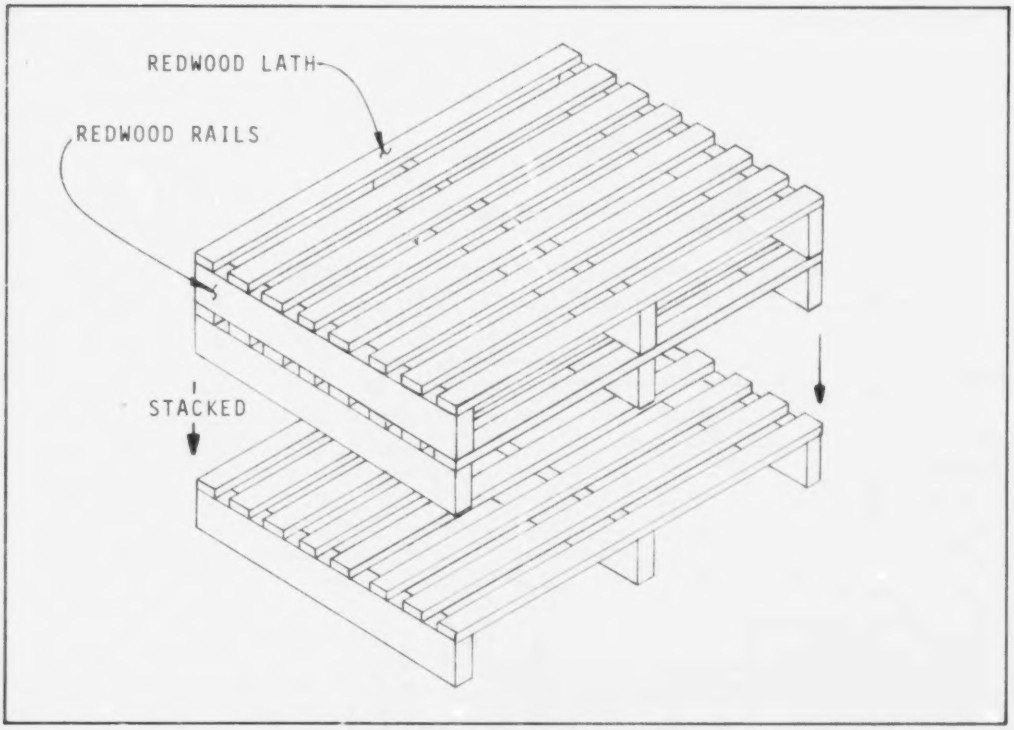
deeper beds; a greater BOD removal in a given volume of media; chemically resistant; and an ability to handle high-strength wastes, such as those from the food processing industry.

Redwood lath media.

One type of manufactured media is redwood laths constructed into 4 x 4 foot racks with spacer rails between layers and space between the laths allowing for air circulation and water flow. The racks are stacked vertically with laths and spacer rails. The rough-sawn texture of the redwood enhances the retention of slime growths. Figure III-5 illustrates the redwood lath media.

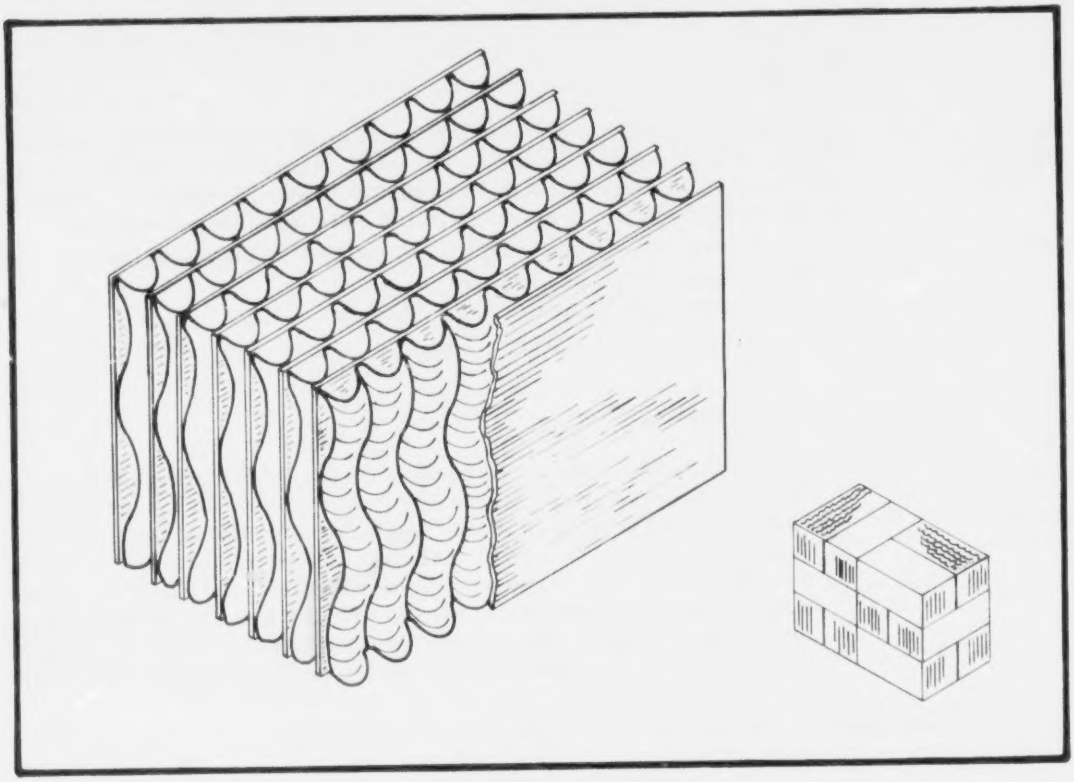
Plastic media.

The molded plastic media consists of modules of interlocking or bonded corrugated sheets of plastic arranged somewhat like a honeycomb. The modules of media are stacked so that they interlock and fit the filter configuration. The corrugated surface of the plastic media enhances the retention of the slime growths. Filters utilizing plastic media are often constructed 15 to 30 feet deep, thus the terms biological or oxidation tower has been introduced to identify these installations. The synthetic media have a higher miminum wetting rate (i.e., rate of flow per unit area) which will maintain a slime growth throughout the media depth for optimum performance. This rate of flow may range from 0.5 to as high as 2.0 gpm/sq. ft. (30 to 125 mgd/acre) depending upon the type and configuration of the media. Design parameters for a specific media are available from the manufacturer. A typical example of plastic media is shown in Figure III-6.



REDWOOD LATH MEDIA

FIGURE III-5



PLASTIC MEDIA

FIGURE III-6

Underdrain

Filter underdrain system must provide adequate removal of effluent and provide adequate air circulation for efficient operation.

The underdrain system collects the filter effluent and transfers it to the subsequent filtration stage or sedimentation tank. The system consists of braces which support the filter media. The floor is sloped to collect the filter effluent in a channel. The underdrain braces may be spaced redwood stringers or slotted blocks constructed of concrete or more commonly, vitrified clay. The underdrain also allows air to circulate through the media to provide the oxygen transfer necessary to maintain aerobic conditions essential to efficient filter operation. Ample underdrain capacity is necessary for rapidly discharging the effluent, and for air circulation and aeration. With natural ventilation, the underdrain system and effluent channel are usually sized such that not more than 50 percent of its cross-sectional area will be submerged at peak hydraulic loading. Some trickling filters have vertical vent pipes around the inner circumference of the structure wall to provide ample ventilation. Other trickling filters have drainage ducts extended through the filter structure wall to provide ventilation.

Ventilation

Proper filter ventilation is a must.

Adequate ventilation is very important in achieving efficient filter operation. Usually, with an adequately sized underdrain system, the difference in air and wastewater temperature will provide adequate natural ventilation. However, forced ventilation may be necessary in some of the following instances:

A. Filters with extremely deep beds, such as the biological towers.
B. Filters situated below grade.
C. Heavily loaded filters.
D. Filters covered by a dome for winter protection, or odor control.

Natural Ventilation

Natural ventilation occurs by differences in temperature.

Natural ventilation occurs by gravity due to the temperature differential between the wastewater temperature and the outside air temperature. The heating or cooling of the air will cause a density change resulting in an air movement (heated air rises and cooled air falls). Therefore, the direction of air flow will depend on the temperatures of the air and wastewater. If the air temperature is warmer than the wastewater temperature, the cooled-air flow will be downward through the filter. If the air temperature is lower than the wastewater temperature, the warmed-air flow will be upward through the filter.

Forced Ventilation

Forced air ventilation should be in the same direction as natural air current.

Usually, forced ventilation systems are designed to provide an air flow of 1 cfm/sq. ft. of filter area with air flow in either direction. The fans should be operated to circulate the air in the same direction as the natural air current. The ventilation units must be equipped with air-tight seals to avoid corrosion problems. At some locations, the air is exhausted through scrubbing towers for the removal of odorous and corrosive gases that are formed in treating the wastes. This is true particularly from food-processing industrial wastewater. During freezing or low air temperatures, it is a wise practice to restrict the air flow to minimize freezing. The volume of air required to sustain an aerobic filter operation is in the vicinity of 0.1 cfm/sq. ft. of filter area. However, this rate will vary depending on the organic loading and microorganism activity in the filter.

Final Sedimentation

Final sedimentation tank is an important unit in the trickling filter process.

The final sedimentation unit is an essential component since trickling filters convert the organic matter to a settleable biomass which periodically or continuously slough (drops) from the filter media. Therefore, the efficiency of the trickling filter process is dependent upon the removal of this sloughed biomass in the final sedimentation unit.

Design is similar to primary tanks.

The design and construction of the sedimentation unit is similar to that of primary sedimentation tanks. Determination and review of the clarifier loading parameters is discussed in Section 2.05.

TRICKLING FILTER PROCESS
TABLE III-I

FILTER CLASSIFICATIONS AND CHARACTERISTICS

PARAMETER	UNITS	LOW-RATE	HIGH-RATE	ROUGHING-RATE
Type of Media		Crushed rock, cinders, slag, or field stone	Crushed rock, cinders, slag, field stone, redwood lath or blocks, or molded plastic.	Any of the previously given materials
Media Depth	ft. (m)	5 to 1 (1.5 to 3.0)	3 to 8 (0.9 to 2.4)	10 to 30*** (3.0 to 9.1)
Organic* Loading	lb BOD/day/1000 cu. ft. (kg BOD/m^3 d)	5 to 25 (0.08 to 0.4)	25 to 100 (0.4 to 1.6)	100 plus (1.6 plus)
Hydraulic Loading	gpd/sq. ft. (m^3/m^2 d)	25 to 100 (1.0 to 4.1)	100 to 1000 (4.1 to 40.7)	700 to 3000*** (28.6 to 122.2)
Recirculation Ratio	R/Q **	Sometimes included	0.5 to 2.0	0.5 to 4.0
Sloughings		Intermittent Brown in color, well-stabilized	Continuous Brown in color, unstable	Continuous Brown in color, highly unstable
Clarifier Surface Overflow Rate	gpd/sq. ft. (m^3/m^2 d)	1000 (40.7)	800 (32.6)	1000 (40.7) (may not be included)
BOD Removal (Includes Sedimentation)	Percent	80 to 90	65 to 85	40 to 70

*The organic loadings given are typical for regions having mild winters. Lower loadings are required in regions having low winter temperatures.

**Recirculation ratio = Recirculation flow divided by raw wastewater flow.

***Applicable to synthetic media-filled roughing filters. Refer to "High-Rate" column for data pertaining to rock-filled roughing filters.

3.03 TRICKLING FILTER CLASSIFICATION

Three general classes of trickling filters.

Trickling filters are generally classified as low-rate, high-rate, or roughing-rate. These classifications are related to the application rate of the hydraulic and organic loadings on the filters. Loading parameters and other operational characteristics for various filter classifications are given in Table III-1. Trickling filters may be further categorized as follows:

A. Depth
B. Number of Stages
C. Media Type
D. Recirculation Flow Scheme
E. Distribution - Fixed or Revolving
F. Dosing Frequency - Intermittent or Continuous

Common ways to express trickling filter loading.

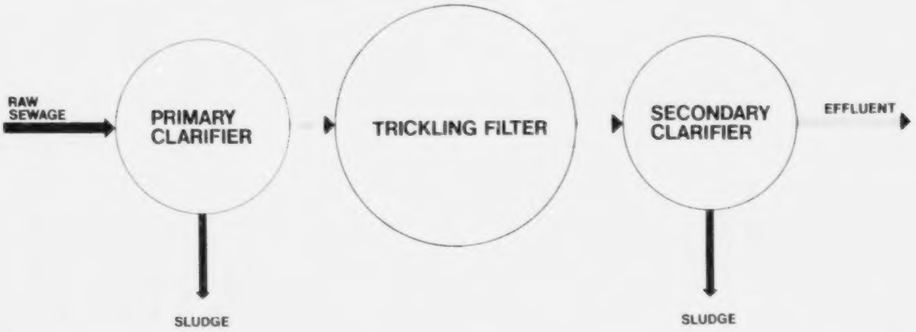
The organic load on a filter is usually expressed as the measurement by weight of BOD applied per unit volume of filter media. The Water Pollution Control Federation *Manual of Practice No. 6*, expresses organic loading as pounds of BOD per day (in waste applied) per 1000 cubic feet of filter media volume (lb BOD/day/1000 cu. ft.).

Low-Rate Trickling Filters

How trickling filters came about.

Trickling filters probably originated from the use of intermittent sand filters. The wastewater was allowed to pass through two or more feet of coarse sand where the microorganisms converted the organic matter into stable end products. The need for greater removal per unit volume of filter media prompted the innovation of contact filters which were basins filled with rock.

The famed Lawrence Experiment Station of the Massachusetts State Board of Health is generally credited with setting up the first experimental trickling filter. They demonstrated that a slow movement of wastewater through a gravel media coated with a biological slime would produce an increase in removing BOD from the wastewater. This concept was improved by an Englishman, Joseph Corbett, by the innovation of a spray distribution system and a false bottom underdrain system.



LOW-RATE TRICKLING FILTER

FIGURE III-7

How a low-rate filter operates.

Low-rate filters are not usually equipped for recirculation except for the return of the sedimentation unit underflow (sludge) to the plant headworks. Some plants do practice recirculation, however, mostly during low flow periods. Recirculation prevents the biological slime from drying out and thus improves filter performance. Generally, a thick, heavy biological growth is developed on the filter media with only a periodic sloughing. A seasonal change in temperature or wastewater application rate will cause large amounts of the biological growth to drop from the filter media. Such an unloading is especially noticeable in the spring and fall. The filter sloughings are usually well oxidized and settle readily.

Biological activity and efficiency of a low-rate filter.

Most of the biological activity in a low-rate filter occurs in the upper three feet of the filter-bed allowing the autotrophic nitrifying bacteria to grow in the lower portion of the filter. A properly loaded and operated low-rate trickling filter process will consistently produce a high-quality, well-nitrified effluent with a BOD and a suspended solids content in the range of 20 to 25 mg/l.

Odors and flies common to process.

The low-rate filter is a highly reliable biological process with the ability to consistently produce a high quality effluent even with fluctuating loading rates. Proper control measures must be taken to minimize nuisances, such as odors and filter fly breeding which are common to low-rate filters.

High-Rate Trickling Filters

Concepts of a high-rate filter process.

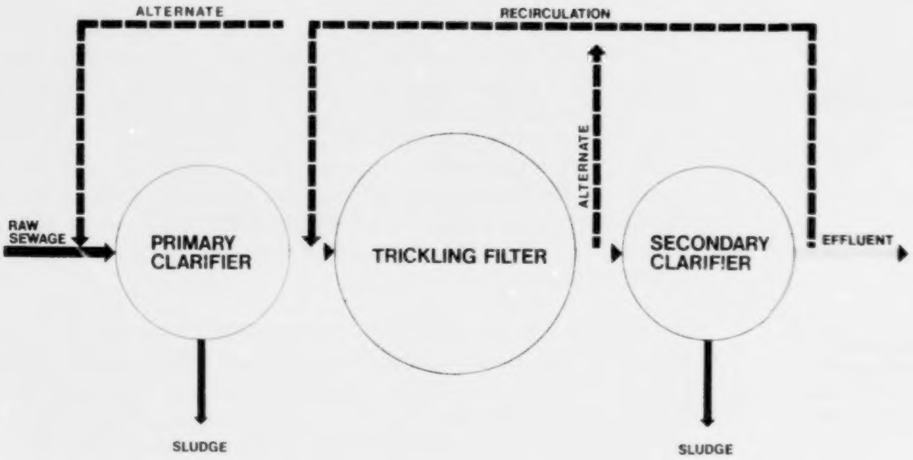
By using in-plant recirculation to dilute the influent organic strength and to keep the media voids flushed, high-rate trickling filters allow greater BOD loadings per volume of media. Recirculation also results in the return of active microorganisms to seed the filter and aids in the prevention of odors and flies. High-rate filters may be either single-stage or two-stage. The two-stage design is capable of achieving the same removal rates as the low-rate filter. However, nitrification does not generally occur unless the BOD loading to the second stage is sufficiently reduced.

How a high-rate filter operates.

High-rate trickling filters are generally designed to receive a continuous flow of wastewater. All high-rate filters are equipped for recirculation, although some utilize this feature only during periods of low flow (See Figure III-8 for typical recirculation schemes for High-Rate Trickling Filters). The recirculation system is commonly designed to provide a ratio of 0.5 to 2. Some systems, however, utilize recirculation to maintain a constant hydraulic loading on the filter. The depth of media in a high-rate filter ranges from three to eight feet, with most filters in the three to five foot range. To avoid clogging and improve ventilation, a larger size media is used. The media is usually relatively uniform and in the range of three to five inches.

A high-rate filter sloughs almost continuously.

Due to the greater hydraulic loading, the excess biological growths are flushed from the media on a nearly continuous basis. This sloughed material is not fully oxidized, and has a high BOD content which can cause problems in the sedimentation unit. Although not as dense as the low-rate filter, the high-rate filter sloughings still settle readily. A single-stage, high-rate filter process usually has a BOD removal efficiency of 65 to 85 percent and seldom exhibits any significant degree of nitrification. A two-stage, high-rate filter process may attain BOD removal efficiencies of 75 to 90 percent with varying degrees of nitrification which depends on the organic loading, filter depth, and wastewater temperature.



HIGH-RATE TRICKLING FILTER
FIGURE III-8

There are a number of patented modifications of recirculation schemes to the high-rate trickling filter process. Some of these recirculation schemes are shown on Figure III-9. A brief discussion of these modifications follows:

Aero-Filter

Recirculation to front of filter during low flows.

The distinguishing feature of this process is the method of spraying the wastewater over the media. Specially designed distributors are usually utilized to provide a "raindrop" application on a maximum surface area at one time. Recirculation (from the final sedimentation tank to the filter influent) is practiced only during periods of low flow to maintain a minimum hydraulic loading of 13 mgad. This procedure allows for an efficient distributor operation. A deep media bed of 8 feet is recommended for the Aero-Filter with a minimum depth of 6 feet. The second filter of a two-stage system may have a minimum depth of 5 feet.

Bio-Filter

Recirculation to front of primary sedimentation tank.

The Bio-Filter has a relatively shallow media bed of 3 to 5 feet. The distinguishing feature of this process is the method of recirculation. Filter effluent, or final sedimentation tank effluent, is returned to the head of the primary sedimentation tank. This method of recirculation requires larger sedimentation units than normal; however, better sedimentation operation can be attained during periods of low flow.

Accelo-Filter

Recirculation to front of filter continuously.

The Accelo-Filter has a relatively deep bed depth, generally about 6 feet. The distinguishing feature of this process is the method of recirculation. The filter effluent is returned to the inlet of that filter or a preceding filter where it mixes with the raw wastewater. A recirculation ratio of 2 to 1 is recommended. This method of recirculation reduces filter odors and fly breeding, and increases the dissolved oxygen concentration. The recirculation also continuously reseeds the influent filter flow with active microorganisms sloughed from the fiter without affecting the hydraulic loading on the primary or final sedimentation tanks.

Roughing-Rate Trickling Filters

Roughing filters are used to buffer high loadings on subsequent biological processes.

Roughing filters are usually designed as an intermediate stage of treatment, and many times precede activated sludge treatment or second-stage filters. Their primary function is to reduce high organic loadings on a subsequent treatment process. Often, roughing filters are utilized at plants receiving high-strength industrial wastes. A roughing filter may be either a rock-filled filter or a synthetic media-filled tower receiving a very high organic loading. Roughing filters have a very high BOD removal efficiency. Generally, a BOD removal of 40 to 70 percent can be expected from a roughing filter process that includes sedimentation.

Figure III-10 shows a typical roughing filter installation.

See Figure III-11 for towers.

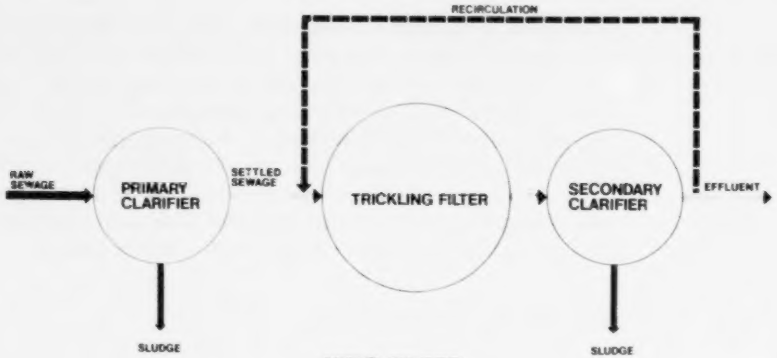
With the introduction of various types of synthetic media, a new concept in trickling filters has been developed. The synthetic media possesses a greater surface area and void space than the conventional crushed rock media. This allows a greater growth of biological slime per unit volume and permits greater hydraulic loadings on the filter without obstructing air flow and oxygen transfer. The synthetic media is lightweight, permitting the construction of deeper filter beds, resulting in smaller diameter units. The increased depth is required to provide sufficient contact time at the higher hydraulic loadings. As the recommended bed depths for synthetic media are 15 to 30 feet, the resulting tower-like structures are sometimes referred to as biological oxidation or roughing towers. The most important application of the biological towers has been as roughing units to absorb toxic or unusually strong industrial wastes and high soluble BOD wastes from food processing industries.

Roughing towers can buffer the activated sludge process.

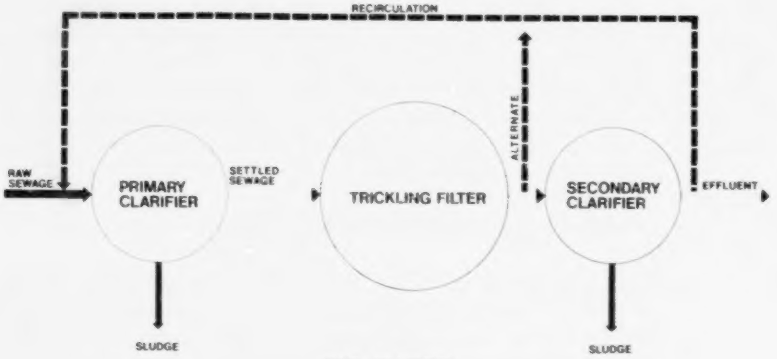
At San Pablo, California, a roughing tower buffers the activated sludge process by absorbing shock loads. Toxic wastes occasionally kill the organisms in the upper portion of the roughing tower; however, the following activated sludge process is protected and the roughing tower readily recovers.

Roughing tower is also capable of producing high-quality effluent.

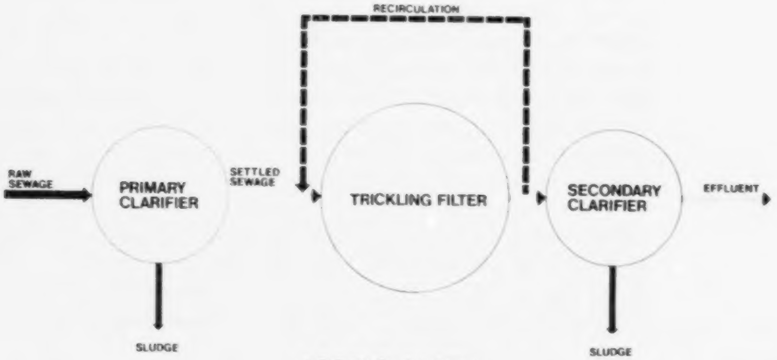
The synthetic media filters are not limited to use as roughing filters; they are capable of producing a high-quality effluent with BOD loadings in the high-rate range. Biological towers utillzing plastic packing at 50 to 100 lbs BOD/1000 cu. ft./day are capable of achieving approximately the same performance as rock-filled filters with an organic loading of 30 to 60 lbs BOD/1000 cu. ft./day.


RECIRCULATION
RAW SEWAGE
PRIMARY CLARIFIER
SETTLED SEWAGE
TRICKLING FILTER
SECONDARY CLARIFIER
EFFLUENT
SLUDGE
SLUDGE

AERO-FILTER


RECIRCULATION
ALTERNATE
RAW SEWAGE
PRIMARY CLARIFIER
SETTLED SEWAGE
TRICKLING FILTER
SECONDARY CLARIFIER
EFFLUENT
SLUDGE
SLUDGE

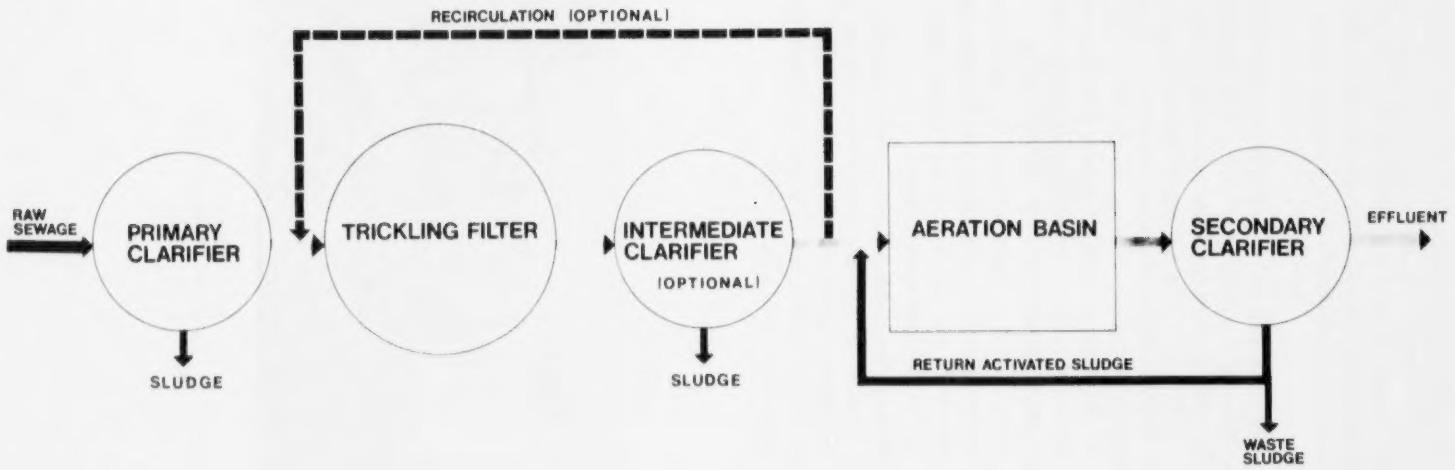
BIO-FILTER


RECIRCULATION
RAW SEWAGE
PRIMARY CLARIFIER
SETTLED SEWAGE
TRICKLING FILTER
SECONDARY CLARIFIER
EFFLUENT
SLUDGE
SLUDGE

ACCELO-FILTER

TRICKLING FILTER VARIATIONS

FIGURE III-9


RECIRCULATION (OPTIONAL)
RAW SEWAGE
PRIMARY CLARIFIER
SLUDGE
TRICKLING FILTER
INTERMEDIATE CLARIFIER (OPTIONAL)
SLUDGE
AERATION BASIN
SECONDARY CLARIFIER
EFFLUENT
RETURN ACTIVATED SLUDGE
WASTE SLUDGE

TYPICAL ROUGHING FILTER INSTALLATION

FIGURE III-10

Figure III-11 is a photograph showing the oxidation (biological) towers used at Fairfield, California to buffer and reduce the organic loading of high-strength brewery waste on the activated sludge process. The air scrubber towers (center) are used to avoid odor nuisances. These oxidation towers are covered and utilize forced ventilation for exhausting the foul air through the scrubbing towers.

tion is used to maintain biological growth throughout depth of media.

Recirculation is utilized to provide the hydraulic wetting rate that will maintain the growth of a biological slime throughout the depth of the media. This minimum wetting rate depends on the type and shape of the media. The BOD removal efficiency of a biological tower is greatly dependent on the maintenance of a healthy biological slime throughout the media depth, as well as the wastewater characteristics, mode of recirculation, and type of synthetic media. A decrease in BOD removal may accompany wetting rates that are greatly above or below the minimum wetting rate. Modes of recirculation may include one or a combination of the following:

1. Return of the tower effluent to the tower influent to seed the media slime growth with suspended biological (sloughings) growths.
2. Return of the clarifier effluent to the tower infuent to dilute the strength of the influent wastewater.
3. Return the sedimentation unit underflow to the tower influent for the build-up of microorganisms to absorb shock loads, and to improve efficiency. Sometimes, the underflow may be reaerated prior to returning in the tower influent. This will provide additional buffering for periods of shock loading.

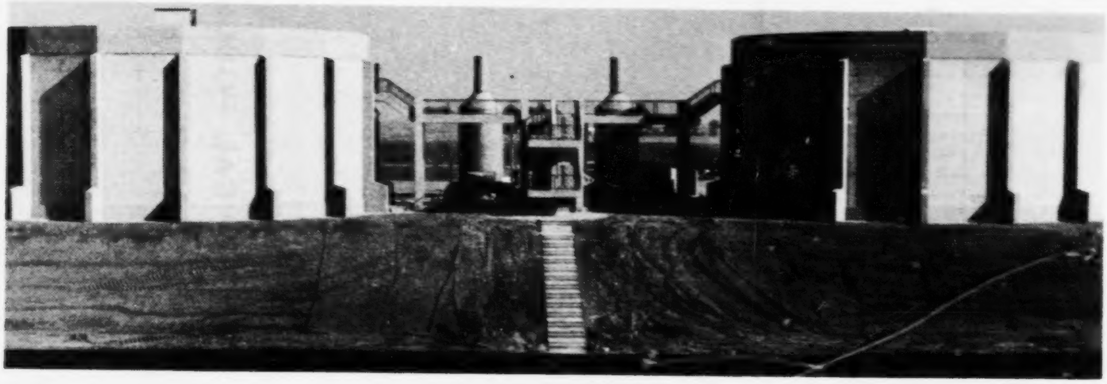


Figure III-11
Oxidation (Biological) Towers

REFERENCES

Eckenfelder, W.W., *Biological Waste Treatment,* Pergamon Press, New York, 1961.

Environmental Protection Agency, *Process Design Manual for Upgrading Existing Wastewater Treatment Plants,* 1974.

Hammer, Mark J., *Water and Waste-Water Technology,* John Wiley & Sons, Inc., New York 1975.

Hawkes, H.A., *The Ecology of Waste Water Treatment,* Pergamon Press, Oxford, 1963.

Kerri Kenneth D., et al., *A Field Study Training Program, Operation of Wastewater Treatment Plants,* (Chapter 6), Sacramento State College Department of Civil Engineering.

Lohmeyer, George T., *Trickling Filters and Their Operation,* Water & Sewage Works, October 1958.

McKinney, Ross E., *Microbiology for Sanitary Engineers,* McGraw-Hill Book Company Inc., New York, 1962.

Metcalf & Eddy, Inc., *Wastewater Engineering,* McGraw-Hill, New York, 1972.

Minch, V.A., Egan, John T., and Sandlin, McDewain, *Design and Operation of Plastic Media Filters,* Journal WPCF, Vol. 34, No. 5, May 1962.

Public Works Journal Corporation, *Handbook of Trickling Filter Design,* 1970.

Reynolds L.B., and Chipperfield, P.N.J., *Principles Governing The Selection of Plastic Media for High-Rate Biological Filtration,* 1970.

Schulze, K.L., D. Sc., *Trickling Filter Theory,* Water & Sewage Works, R256, October, 1960.

The Texas Water Utilities Association, *Manual of Wastewater Operations,* (Chapter 12), 1971.

Water Pollution Control Federation, *Manual of Practice No. 6, Units of Expression for Wastewater Treatment,* 1976.

4.01 INTRODUCTION

Laboratory control is an essential tool.

An essential tool for proper process control is frequent and accurate sampling and laboratory control tests. By relating the lab test results to operation, the operator can select the most effective operational parameters, determine the efficiency of his treatment processes, and identify developing problems before they seriously affect effluent quality. Therefore, laboratory facilities play an important role in the control of an aerobic biological treatment facility.

4.02 LABORATORY SAMPLING AND TESTING PROGRAM

Good sampling procedures are essential.

Good sampling procedures are the key to meaningful laboratory analyses. A typical sample represents only a small fraction of the total flow, and great care must be exercised to ensure that the sample is representative. If this is not accomplished, the subsequent analytical data is worthless for process control. Therefore, the importance of good and accurate sampling techniques cannot be overstressed.

The exact location of sampling points within a given treatment plant cannot be specified because of the varying conditions and the plant design. However, it is possible to present certain general guidelines which are presented on Figure IV-1.

Two types of samples.

Two types of samples may be collected, depending upon the purpose of sampling. The first is a dip or "grab" sample which consists of a single portion collected at a given time. The second type of sample is a "composite" sample that consists of portions taken at known times and then combined in volumes that are proportional to the flow at the time of sampling. These combined portions produce a sample which is representative of the wastewater characteristics over the entire sampling period.

24-hour composite sampling is preferred.

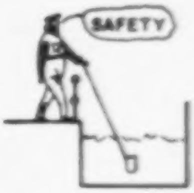
The preferred sampling procedure, except for certain lab or field tests which must be run immediately (Dissolved Oxygen, Temperature, pH), is to collect hourly samples over a day, having sample volumes that are in proportion to the wastewater flow rate. When available and where possible, automatic sampling devices should be employed. The sample containers and sample lines should be thoroughly cleaned each time to prevent sample contamination. The hourly grab samples should be composited into a labeled plastic gallon bottle and kept refrigerated at 3 or 4° C. to prevent bacterial decomposition. For some tests (such as the nitrogen tests), other methods of preservation may be needed, refer to Standard Methods for recommended preservation procedures. A final composited sample volume of 2 to 3 liters is usually sufficient to perform all routine tests. Where collection of an hourly sample is not feasible, a 2 or 3 hourly sampling procedure is the next best alternative. The sampling method and time of sampling should be noted upon the lab record (log) sheet as reference for later data review and interpretation.

If only grab samples are collected, the operator must sample during peak flow conditions.

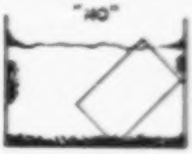
Grab Samples

Grab samples are representative of the instantaneous characteristics of the wastewater. If it is only possible to collect grab samples, they should be collected when the treatment plant is operating at peak flow conditions.

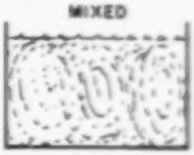
Sampling point should be readily accessible and adequate safety precautions should be observed.



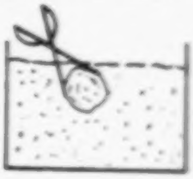
No deposits or materials should be collected from the side walls or the water surface.



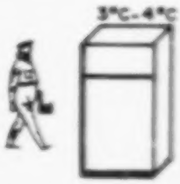
Sample must be taken where the wastewater is mixed and of uniform composition.



Large or unusual particles should not be collected with routine samples.



Sample should be delivered and analyzed as soon as possible. Stored samples must be refrigerated at 3 to 4° C.



WASTEWATER SAMPLING GUIDELINES

FIGURE IV-1

Sample collection should be conducted systematically at various sampling locations during the flow sequence through the plant. Grab sampling times may be systematically staggered to account for the respective hydraulic detention time of each unit process. In this manner, a slug of water may be theoretically followed through the treatment plant. For example, if the hydraulic detention period through a particular unit process is two hours, then the grab sample of the effluent from this unit should be collected two hours after the influent sample. In this manner, the samples can be assumed to be representative of the wastewater before and after treatment.

Composite Samples

24-Hour composites are the best for determining organic loading and performance.

Composite samples generally represent the wastewater characteristics over a specified period of time. The ideal procedure incorporates the use of 24-hour composite samples consisting of hourly grab samples proportioned to the flow at the time of sampling. This procedure is only feasible in treatment facilities with 24-hour attendance or where automatic samplers are warranted. Adequate results, however, can generally be obtained from analysis of composite samples collected over a shorter period. In those facilities where automatic samplers are not available, collection of composite samples during the number of shifts worked would be sufficient as long as peak flow periods are included. A total composited sample volume of approximately three liters is generally sufficient to perform the routine process control tests.

The total amount of sample required, the number of samples required, the rate of flow at the time of sampling, and the estimated average daily flow rate, can be used to calculate the amount of sample to be collected during each sampling period to represent the daily flow from the following equation:

$$\text{Amount of sample to collect, ml} = \frac{(\text{Rate of flow, mgd @ time of sampling})(\text{Total sample required, ml})}{(\text{Number of samples collected})(\text{Average daily flow, mgd})}$$

Example Calculation

Calculation for composite sampling.

A. Data Required
   1. Rate of flow at time of sample collection = 1.5 mgd
   2. Total sample volume required = 3 liters or 3000 ml
      Note: ml = (liters) (1000)
   3. Number of samples to be collected = 8
   4. Average daily flow = 0.9 mgd

B. Determine the amount of sample to be collected for the present flow rate in milliliters.

$$\text{Amount of sample to collect, ml} = \frac{(\text{Rate of flow, mgd})(\text{Total sample required, ml})}{(\text{Number of samples})(\text{Ave. daily flow, mgd})}$$

$$= \frac{(1.5\ \text{mgd})(3000\ \text{ml})}{(8)(0.9\ \text{mgd})}$$

$$= 625\ \text{ml}$$

Laboratory Control Program

Lab control requires adequate facilities and technical skills.

The specific laboratory tests and frequency which they are performed for process control and performance evaluation will vary from plant to plant depending on the type of trickling filter process, plant size, laboratory facilities, available manpower, and technical skills. Minimum sampling and testing programs for typical trickling filter processes are presented on Figure IV-2.

Low-Rate Trickling Filter Process

Minimum tests for low-rate filters.

The low-rate trickling filter process does not require complicated or stringent process control measures. However, the process does require daily attention to maintain efficient and trouble-free operation. At a smaller plant, the following tests would be sufficient in evaluating the performance of a low-rate filter process:

- BOD
- Settleable Matter
- Suspended Matter
- Temperature
- pH
- Dissolved Oxygen

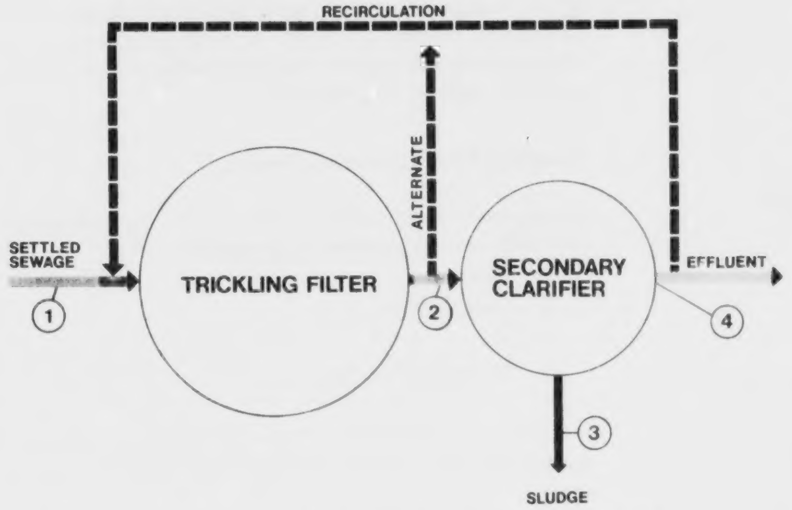
At a larger plant, the laboratory control program should also include ammonia and nitrate nitrogen determinations. The presence of 2 to 15 mg/l of nitrate nitrogen in the filter effluent usually indicates a high degree of stabilization. A typical sampling and testing program may be developed for a low-rate filter process by referring to Figure IV-2.

High-Rate Trickling Filter Process

Minimum tests for high-rate filters.

Like the low-rate trickling filter process, the high-rate process requires limited daily maintenance for an efficient and trouble-free operation. The recirculation flow scheme and rate should be regulated to attain the best possible performance at the least expense. At single-stage trickling filter plants. the following tests would be sufficient in evaluating the filter performance:

- BOD
- Settleable Matter
- Suspended Matter
- Temperature
- pH
- Dissolved Oxygen



SAMPLE LOCATIONS FOR TYPICAL TRICKLING FILTER PROCESS

DESCRIPTION	SETTLED SEWAGE (PRIMARY EFFLUENT)	FILTER EFFLUENT	SLUDGE (UNDER FLOW)	SECONDARY CLARIFIER EFFLUENT	FREQUENCY 1 TO 5 MGD	FREQUENCY 5 MGD AND LARGER	TYPE OF SAMPLE	METHOD OF TEST	APPLICATION OF TEST
FLOW	CR	–	–	CR	–	–	–	–	P
B O D	☒			☒	1 / W	2 / W	C	AM	P
C O D	☒			☒	1 / W	2 / W	C	AM	P
SUSPENDED SOLIDS TOTAL	☒	☒		☒	1 / W	2 / W	C	AM	P
SUSPENDED SOLIDS VOLATILE	☒			☒	1 / W	2 / W	C	AM	P
SETTLEABLE SOLIDS	☒	☒		☒	D	D	C	AM	P
AMMONIA ●	☒			☒	2 / M	1 / W	C	AM	P
NITRITE ●				☒	2 / M	1 / W	C	AM	P
NITRATE ●				☒	2 / M	1 / W	C	AM	P
PHOSPHORUS	☒			☒	2 / M	1 / W	C	AM	P
D O				☒	1 / W	2 / W	G	AM	P
pH	☒		☒	☒	D	D	G	AM	S
TEMPERATURE	☒			☒	D	D	G	AM	S
TOTAL & VOLATILE SOLIDS			☒		1 / W	2 / W	C	AM	P
LOCATION OF SAMPLE	①	②	③	④					

● NOT APPLICABLE TO SINGLE-STAGE HIGH-RATE AND ROUGHING-RATE FILTERS

CODE DESCRIPTION			
☐	SAMPLE	S	SURVEILLANCE
☒	TEST RESULTS CALCULATED	W	WEEK
②	DENOTES SAMPLE LOCATION	M	MONTH
C	COMPOSITE	AM	ANALYTICAL MEASUREMENT
D	DAILY	CR	CONTINUOUSLY RECORDED AND TOTALIZED
G	GRAB	MM	MAKE MEASUREMENT
P	PROCESS CONTROL	PM	PHYSICAL MEASUREMENT

SAMPLING AND TESTING PROGRAM FOR
TRICKLING FILTER PROCESS

FIGURE IV-2

At two-stage filtration plants where nitrification is being achieved, the laboratory control program should also include ammonia and nitrate nitrogen determinations. For development of a typical sampling and testing program, refer to Figure IV-2.

Roughing Filters/Biological Towers

Minimum tests for roughing towers.

The following laboratory tests will be valuable in performance evaluation of a filter being operated as a roughing unit:

- BOD
- Temperature
- pH
- Dissolved Oxygen

If solids sedimentation occurs, the following tests should also be included to monitor the sludge removal and effectiveness of the sedimentation unit:

- Settleable Matter
- Suspended Matter

For development of a typical sampling and testing program refer to Figure IV-2.

Minimum tests for a biological tower.

In a biological tower where the sedimentation unit underflow (settled matter) is returned to the tower influent, process control is somewhat more difficult and requires a more stringent monitoring program. The mixing of these flows results in a biological mass similar to that of mixed liquor in the activated sludge process. The following laboratory tests would be valuable in performance evaluation and process control:

- Suspended matter and BOD of the influent and effluent flows.
- Suspended matter concentration of the tower effluent flow.
- Suspended matter concentration of return sludge flow.
- Settleability (settlometer) test of the tower effluent flow.
- Dissolved oxygen of tower effluent and before effluent weir in clarifier.

Process control concept.

Process control primarily consists of the operator selecting and maintaining the recycle rates and the suspended matter concentration in the tower effluent flow that produces a sludge with good flocculating and settling characteristics, and consequently an acceptable quality of effluent. The excess filter sludge (amount of sludge equal to that produced each day) is usually wasted from the system on a daily basis. For laboratory and process control procedures, and sampling and testing program refer to the "ACTIVATED SLUDGE PROCESS" division, Sections II and IV.

4.03 LABORATORY CONTROL TESTS

This section of the manual is provided to increase understanding and to develop an appreciation of laboratory control tests.

Sampling and analyses must be increased when the process is upset.

The tests discussed are those necessary for routine process control when the biological system is operating properly. Additional analyses and increased frequency of analysis for the routine analysis may be required for abnormal conditions. Specific suggestions are made for abnormal operation in Section I, "TROUBLESHOOTING." However, the operator must rely upon his own judgment to determine which analyses he needs to conduct to supply the information that he desires.

Typical worksheets provided.

Typical worksheets have been provided in Appendix A to assist the operator in developing systematic data collection, calculation, and recording. Precautionary procedures are presented for each of the tests presented in this section to make the operator aware of the common pitfalls. Except where a specific note is made, all analyses are referenced to the fourteenth edition of "Standard Methods for the Examination of Waters and Wastewaters."

Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand is determined by incubating a sample of known volume in the presence of microorganisms, excess nutrients, and dissolved oxygen. A properly conducted BOD analysis will have organic matter as the growth limiting substance. If oxygen is limiting, the analysis is not meaningful.

The 5-Day BOD.

The BOD is an index of the amount of oxygen that will be consumed by the decomposition of the organic matter in a wastewater. The analysis consists of measuring the initial dissolved oxygen concentration, incubation for five days at 20° C, and measuring the final dissolved oxygen. The difference in dissolved oxygen concentration corrected for the initial dilution is called the BOD. The BOD test is related to both the organic loading upon the biological process as well as the removal efficiency of the process. The difference between the BOD applied and the BOD leaving the process is equal to the BOD removed by the process. The difference is part of the data required to determine the loading upon the process. For example, the organic loading upon the trickling filter process is expressed as the pounds BOD applied per day per 1000 cubic feet of filter media. Historically the organic loading on a trickling filter has been expressed as BOD applied. The efficiency of the process is determined by the following formula:

Calculating removal efficiency.

$$\frac{\text{BOD applied, lb/day - BOD leaving, lb/day} \times 100}{\text{BOD applied, lb/day}} = \text{the removal efficiency, \%}$$

In this determination, the combined efficiency of the trickling filter and clarifier are considered.

Precautionary Procedures

When performing BOD analyses the following procedures should be followed in conjunction with the procedures outined in Standard Methods.

Minimum of two dilutions, at least 2 mg/l D.O. used—must be at least 2 mg/l left after 5-days.

1) A minimum of two dilutions per sample should be used. Only analyses with oxygen depletions of greater than 2 mg/l but with no less than a residual of 2.0 mg/l after five days of incubation at 20° C should be used to calculate the BOD. Generally, the highest value calculated should be used to represent the BOD.

Mix samples well.

2) Samples should be well mixed before the dilutions are made. A wide tip pipette should be used for making the dilutions. The wide tip does not clog with suspended solids.

Avoid aeration during bottle filling.

3) Samples and the dilution water must be carefully added to the BOD bottle to avoid aeration and the possibility of entraining bubbles in the solution.

Note 5-Days mean 120 Hours.

4) The BOD incubator *must* be maintained at 20° ± 1° C for the entire 5 day (Note: 120 hours) period. Record the temperature of the incubator from a NBS certified thermometer placed in a beaker of water in the incubator.

Toxic slide.

5) IF the BOD value of the more dilute sample is always greater, this may indicate that there is some toxic material in the wastewater, which is inhibiting the bacteria. A series of dilutions should be set up and run. If the BOD is increasing with higher dilution, this may indicate a condition known as a toxic slide. Further analyses should be conducted to determine the nature of the toxic material, and if it appears that the concentration of the toxicant is significant, efforts should be initiated to identify the source and reduce the concentration of the toxicant in the wastewater.

Primary standard made from glucose-glutamic acid.

6) Use of a primary standard is strongly recommended. The standard should be made of glucose—glutomic acid mixture—and it should be made up at a BOD near those levels in the treatment plant influent. The primary standard should be made up and analyzed weekly. Any significant variation (more than ±20%) should cause the operator to be suspicious. Efforts should be undertaken to review the laboratory procedure, and find out what is causing the problem. Each operator should analyze the standard and the results should be within ±10%. Operators not falling within this range should review their laborator techniques and make the appropriate adjustments.

Use allythriourea to inhibit nitrifiers.

7) Wastewaters that have been partially nitrified may produce high BOD results. The increased oxygen demand results from the oxidation of ammonia to nitrate. The use of allylthiourea in the dilution water will inhibit the nitrifiers and alleviate this problem.

Chemical Oxygen Demand (COD)

COD is fast and reproducible.

The COD is an estimate of the total oxygen demand that results from the degradable organic matter. The analysis consists of oxidizing the organic matter with potassium dichromate in a heated strongly acidic solution.

While the BOD analysis is an index of the biodegradable organic matter, it is not very useful for process control because of the five day lag in time. The COD test is rapid (3-4 hours); it is not subject to interferences from toxic materials; and it is not affected by ammonia oxidation.

The COD is better for process control.

The COD removal of a biological process is directly relatable to the amount of biological growth that can result from this removal. The COD analysis suffers from the disadvantage that it does not measure the rate of biodegradability of matter removed and therefore it is difficult to predict the effects of effluents on the oxygen resources of receiving waters and the treatability of a particular wastewater.

Precautionary Procedures

When performing the COD test, the following procedures should be followed in conjunction with those outlined in Standard Methods.

The analyst must establish his variability.

1) Initially, the analyst should run triplicate samples to establish the variability of his analyses. Once this variability is established, samples can be analyzed without replication.
2) Use a wide tip pipette to ensure that a representative sample is taken.
3) Glassware used for the COD analyses must be washed with hydrochloric acid, hot washed, and rinsed three times with distilled water.
4) Extreme caution and safety precautions should be practiced when handling the chemical reagents for the test. Goggles, a rubberized apron and asbestos gloves are essential equipment.
5) If a sample mixture turns green during or immediately following the heating period, the analysis is not valid and should be reexamined in a more dilute sample. If the problem reoccurs then the laboratory technique should be reevaluated and the sample should be checked for likely interferences, such as high chloride concentration or the presence of a strong base.
6) A primary standard consisting of potassium acid phtalate should be analyzed on a weekly basis to ensure that the analyses are consistent. The COD concentration of the standard should be near the level of the COD of the wastewater. (See Standard Methods.)

Soluble COD and BOD

Soluble COD and BOD.

The discussions on BOD and COD have been limited to the measurement of the total COD and BOD. The soluble BOD and COD are more meaningful for measuring performance. The soluble BOD or COD is determined in exactly the manner descried above, except that the sample is filtered through a membrane filter prior to the analysis. The use of this filtering apparatus is discussed under the suspended matter analysis.

Settleable Matter

The settleable matter test (also known as the Imhoff Cone Test) is a measure of the volume of solid matter that settles to the bottom of an Imhoff cone in one hour. The volume of settled solids is read as milliliters per liter (ml/l) directly from the graduations at the bottom of the Imhoff cone.

How to make a quick check on Sedimentation Unit operation.

This test is of value in providing a quick and efficient check of a sedimentation unit. Additionally, a rough estimate of the volume of solids removed by the sedimentation unit can be made. Only a trace of settleable solids should remain in the secondary effluent, and very little should remain in the primary effluent. Poor settleable matter removal may indicate the following related problems which may occur in sedimentation basins:

Symptoms—highlighted by settleability test.

Primary and Secondary

1) Hydraulic overload.
2) Irregular flow distributions to multiple units.

3) Excessively high velocity currents.
4) Effluent weirs of uneven height - short circuiting.
5) Improper sampling technique.
6) Improper raw sludge removal rates.

Secondary Only

1) Biological upset.

Precautionary Procedures

When performing the settleable solids test, the following procedures should be followed in conjunction with those outlined in Standard Methods.

1) Take a sample volume greater than one liter.
2) Use grab samples for this analysis.
3) Fill the Imhoff cone exactly to the one liter mark in one rapid pouring without stopping.
4) After the sample has settled for 45 minutes, either gently tap the sides of the cone or gently spin the cone between the palms of your hands to settle those solids adhering to the sides of the cone above the compacted settled layer at the bottom of the cone.
5) Read and record the volume of settled matter (ml/l) at the end of one hour. Read the graduation at the average solids depth and not at a peak or void area on the surface of the settled solids.

Total Suspended Matter

Measure of the filterable solids.

The suspended matter test refers to the solids in suspension that can be removed by standard filtering laboratory procedures. The suspended matter is determined by filtering a known volume of sample through a weighed glass-fiber or membrane filter disc in an appropriate filtering apparatus. The filter with the entrapped solids is oven-dried at 103° - 105° C and then cooled in a desiccator and subsequently weighed. The increase in filter weight represents the suspended matter.

The significance of the suspended matter test is generally dependent on the type of treatment process and the location of measurement within that process application. Results of the test have the following uses in process control:

Use of this test.

1) Evaluating the organic strength of the wastewater.
2) Evaluating clarifier solids loading.
3) Determine the sludge recycle rate by calculation.
4) Calculating clarifier solids capture.
5) Estimating the solids inventory.

Precautionary Procedures

When performing the suspended matter test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) The sample must be thoroughly mixed prior to taking a sample aliquot.

Use wide tipped pipette.

2) Do not use a small-tipped pipette to measure the sample aliquot. A wide-tipped pipette should be utilized to permit passage of the larger solids and to facilitate rinsing. An alternate method of obtaining a sample aliquot would be to pour it into a graduated cylinder.
3) Rinse all adhering solids from graduate (or pipette) with distilled water. Pour rinse water through the filter.
4) Test results that appear faulty or questionable should be disregarded.

Temperature between 103-105° C.

5) It is important to always maintain a temperature of between 103 - 105° C in the drying oven. The temperature must be monitored and recorded in a record book.
6) Be sure that the paper filter is properly seated in the filtration apparatus before pouring the sample. This is easily accomplished by wetting the filter paper with distilled water, then applying vacuum to the filtration apparatus.
7) Samples containing high solids levels may require more than one hour to completely dry.
8) Be consistent in the length of time the filter apparatus and paper are allowed to cool in the dessicator both before and after filtering.
9) Use Whatman GF/C filters and a millipore filter apparatus with sintered glass seat for this analysis.

Nitrite Nitrogen

NO_2 a partially oxidized form of nitrogen.

Nitrite (NO_2) is an intermediate oxidation state of nitrogen between ammonia nitrogen and nitrate nitrogen. Nitrite is transatory and readily amenable to both bacterial oxidation to nitrate or reduction to nitrogen gas depending upon environmental factors such as dissolved oxygen and microbial conditions.

High NO_2 concentrations imply incomplete nitrification.

The nitrite concentration can be used to monitor how well nitrification is progressing in a treatment process. High nitrite concentrations indicate incomplete nitrification, and could lead to problems, such as high chlorine and oxygen demands.

Precautionary Procedures

When performing the nitrite nitrogen test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) Use extreme caution in handling the chemical reagents to avoid injury or damaged clothing.

Analyze as soon as possible.

2) Due to the instability of nitrite (NO_2), the composite samples used for the nitrite analysis should be preserved by one of the following methods: (a) freezing, or (b) 5 ml of chloroform per liter of sample.

Sample must be cool.

3) The samples must be cool when the analysis is performed or erroneous results will be measured.
4) Deviation from standard procedure may yield erroneous results. Be consistent in your laboratory technique.

Nitrate Nitrogen

NO_3 a fully oxidized form of nitrogen.

Nitrate is seldom found in raw wastewater or primary effluent, because facultative microorganisms can readily use nitrate as an oxygen source. In the biological treatment process, the ammonia nitrogen can be microbiologically oxidized to nitrite and then to nitrate depending on the microorganisms present and the environmental factors such as pH, temperature, and dissolved oxygen.

Typical in low rate trickling filters.

Secondary effluent may contain from 0 to 50 mg/l nitrate nitrogen depending on the total nitrogen content in the raw wastewater and conditions of treatment. Low-rate trickling filters with relatively deep beds can produce highly nitrified effluents, while a single-stage, high-rate trickling filter will rarely be capable of nitrifying.

Precautionary Procedures

When performing the nitrate nitrogen test, the following procedures should be followed in conjunction with the procedures outined in Standard Methods.

Use the Brucine Method.

1) Use the Brucine method for routine analysis.
2) Analyze the sample as soon as possible to avoid bacterial reduction of the nitrate.
3) Preserve samples that cannot be analyzed immediately by either freezing or by the addition of 5 ml of chloroform per liter of sample.

Ammonia Nitrogen

This test measures the nitrogen present in the wastewater as ammonia. Ammonia nitrogen in domestic wastewater is generally between 10 and 40 mg/l. Primary treatment may increase the ammonia nitrogen content slightly due to decomposition of some protein compounds during treatment. In secondary treatment process, ammonia can be oxidized to nitrite then to nitrate in varying degrees depending on factors, such as the residence time of the microorganisms, wastewater temperature, and oxygen reliability.

A measure of the form of nitrogen that causes high chlorine demands and fish toxicity.

The significance of this test is associated with the oxygen demand required to oxidize ammonia in the biological treatment process or receiving stream. Theoretically, the oxidation of one pound of ammonia nitrogen requires 4.6 pounds of oxygen. This test is also valuable in evaluating the performance of a treatment process designed to nitrify. Other significant problems relating to ammonia are high chlorine demands, fish toxicity, and high oxygen demand on receiving waters.

Precautionary Procedures

When performing the Ammonia Nitrogen test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) Use extreme caution in handling the chemical reagents to avoid injury or damaged clothing.
2) Deviation from standard procedures may yield erroneous results. Consistency in laboratory techniques is essential.

Total Phosphorus

Essential to biological growth.

Phosphorus is one of the nutrients essential to biological growth in secondary treatment processes. Most wastewaters have more phosphorus available than is required for biological growth and assimilation of the carbonaceous BOD. A deficiency of phosphorus may result from high waste loading from industries, such as canneries which generally have wastes that are high in carbohydrates and low in nutrients. Such a phosphorus defficiency may limit biological growth and lead to poor BOD removals.

Typical raw domestic wastewater contains approximately 10 mg/l of phosphorus of which 20 to 30 percent may be removed by the growth of microorganisms which are wasted from the process. Greater removals may be obtained by various processes involving addition of a metal ion such as iron or aluminum to chemically precipitate iron or aluminum phosphate. Other removal processes involve pH adjustment by addition of lime or other means and chemical precipitation of a calcium phosphate.

Precautionary Procedures

When performing the total phosphorus test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

1) Use extrreme caution in handling the chemical reagents to avoid injury or damaged clothing.
2) Record specific procedures used for pretreatment of sample and measurement of phosphorus concentration with test results. Also, clearly indicate the expression of the test results, P or PO_4. (Note: 1.00 mg/l P equals 3.06 mg/l PO_4.)
3) Deviation from standard procedure may yield erroneous results. Be consistent in your laboratory technique.

Dissolved Oxygen

An important parameter.

Dissolved oxygen (DO) is that oxygen dissolved in liquid and is usually expressed as milligrams per liter (mg/l). There are various tests to determine the DO content of water. Generally, the iodometic methods and the membrane electrode (DO probe) are best suited for the domestic wastewater application. The azide modification of the iodometric method (also known as Winkler Method) is recommended for most wastewater and stream samples. When determining the DO in trickling filter effluent and other biological flocs which have a high oxygen utilization rate, the copper sulfate-sulfamic acid flocculation modification should precede the azide modification to retard biological activity and to flocculate suspended solids. The membrane electrode method is becoming increasingly more popular because of its speed, ease of operation, and adaptability to process control instrumentation. The membrane electrodes must be properly maintained and calibrated on a daily basis to ensure that their measurements are accurate and usable for process control.

DO measurement can be used to control aeration.

The significance of the DO test in process control is in its measurement of the dissolved oxygen available for and essential to aerobic decomposition of the organic matter; otherwise, anaerobic decomposition may occur with the possible development of nuisance conditions. The DO test is also used in the determination of BOD as discussed previously. Fish and most aquatic life require dissolved oxygen to sustain their existence and the DO test is an important measurement in plant effluents and receiving water quality.

Precautionary Procedures

When performing the DO test, the following procedures should be allowed in conjunction with the procedures outlined in Standard Methods.

1) Use extreme caution in handling the chemical reagents to avoid injury or damaged clothing.

Use special care in sampling.

2) The use of special DO sampling equipment is preferable for collecting samples. The samples should be taken with the sample container completely immersed and without aeration of the sample or entrapment of any air bubbles.

Perform immediately after sampling.

3) Perform DO test immediately following collection of sample.
4) The following substances will interfere in the azide modification of the iodometric DO analysis: iron salts, organic matter, excessive suspended matter, sulfide, sulfur dioxide, residual chlorine, chromium, and cyanide.

Hydrogen Ion Concentration (pH)

The intensity of acidity or alkalinity of a solution is numerically expressed by its pH. A pH value of 7.0 is neutral, while values 7 to 14 are alkaline and values 0 to 7 are acid. pH can be measured colorimetrically or electrometrically. The electrometric method (pH meter) is preferred in all applications because it is not as subject to interference by color, turbidity, colloidal matter, various oxidants and reductants as is the less expensive colorimetric method.

An important measure for the microorganism.

The pH measurements are valuable in process control because pH is one of the environmental factors that affect the activity and health of microorganisms. Sudden changes or abnormal pH values may be indicative of adverse industrial discharge of a strongly acid or alkaline waste. Such discharges are detrimental to biological processes as well as to the collection system and treatment equipment, and should be either stopped or neutralized prior to discharge. Generally, the pH of the secondary effluent will be close to 7. A pH drop may be noticeable in a biological process achieving nitrification because alkalinity is destroyed and carbon dioxide is produced during the nitrification process.

Precautionary Procedures

When performing the pH test, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

Use grab samples—analyze immediately.

1) Grab samples should be used for the pH measurement. The pH test should be performed on the samples immediately following collection before the temperature or dissolved gas content can change significantly. Do no heat or stir the pH sample as a change in temperature or dissolved gas content will affect the pH value.

2) Do not contaminate the buffer by pouring the used buffer solution back into the buffer container.

Calibrate the pH meter daily.

3) Calibrate the pH meter daily with a buffer solution of approximately the same temperature and pH as the sample to be tested. Adjust the pH meter's temperature compensator for each pH measurement.

Exercise extreme care with electordes.

4) Avoid fouling the electrodes with oil or grease.
5) Erratic results or drifting should prompt an investigation of the electrodes.

Temperature

Temperature affects growth of microorganisms.

In process control, accurate temperature measurements are helpful in evaluating process performance because temperature is one of the most important factors affecting microbial growth. Generally stated, the rate of microbial growth doubles for every 10° C increase in temperature within the specific temperature range of the microbe. Temperature measurements can be helpful in detecting infiltration/inflow problems and illegal industrial discharges. Thermometers are calibrated for either total immersion or partial immersion. A thermometer calibrated for total immersion must be completely immersed in the wastewater sample to give a correct reading, while a partial-immersion thermometer must be immersed in the sample to the depth of the etched circle around the stem for a correct reading.

If a Fahrenheit thermometer is used its readings may be converted to Centigrade by the following formula:

$$°C = \frac{5}{9}(°F - 32°)$$

Precautionary Procedures

When obtaining the temperature of a sample, the following procedures should be followed in conjunction with the procedures outlined in Standard Methods.

Measure immediately.

1) To attain truly representative temperature measurement, it is necessary either to take the temperature reading at the point of sampling or immediately following sample collection. A large sample volume should be used to avoid a temperature change during the measurement.
2) The accuracy of the thermometer used should be occasionally verified against a precision thermometer certified by the National Bureau of Standards (NBS).
3) The thermometer should be left in the sample while it is read.

Flow

Accurate flow measurements are essential.

A physical measurement of the in-plant flows is essential for true process control. Without these flow measurements, it is impossible to compute hydraulic and organic loadings, detention periods, recycle flows, and clarifier underflows. Without the above parameters to regulate the treatment processes, the operator is left with only a "seat of the pants" approach to process control. Without a measurement of in-plant flows, it is impossible to competently evaluate the operation of the individual treatment units. The measurement of the plant flows also provides a basis for computing costs for billing, estimating chemical needs, predicting the future need for plant expansion or modification, and evaluating the effect of the plant effluent on the receiving stream. Reference to Figure IV-2 will indicate locations of typical in-plant flows that should be measured for process control.

Flow measurements are very important.

How to measure flow without a flow meter.

In many of the smaller plants, only the plant influent flow and possibly the plant effluent flow are metered. In these cases, the operator will have to measure the in-plant flows by other means. For instance, a pumped flow may be estimated by multiplying the pump capacity (gpm) times the minutes of pumping time per day.

$$\text{gpd} = (\text{gpm})(\text{min/day})$$

Often, pump capacity may be estimated by measuring the volume of liquid pumped from or to a structure in a timed period. No unmetered flows into or out of the structure must be permitted during the test period. Metered flows into or out of a structure during the test must be taken into account when computing the volume of liquid pumped.

$$\text{gpm} = \frac{(\text{Area, sq. ft.})(\text{Depth, ft.})(7.48\ \text{gal/cu. ft.})}{\text{minutes}} \pm \text{metered flow, gpm}$$

The metering instrumentation must be properly maintained and calibrated on a regular and routine basis to insure that their measurements are accurate and usable in process control and performance evaluation.

REFERENCES

APHA, AWWA, WPCF, *Standard Methods for Examination of Water and Wastewater*, 14th Edition, 1976.

California Water Pollution Control Association, *Laboratory Procedures for Operators of Water Pollution Control Plants*, 1970.

Kerri, Kenneth, D., et al., *A Field Study Training Program, Operation of Wastewater Treatment Plants*, (Chapters 6 and 14), Sacramento State College Department of Civil Engineering.

New York State Department of Health, *Laboratory Procedures for Wastewater Treatment Plant Operators*, Health Education Service, Albany, N.Y.

New York State Department of Health, *Manual of Instruction for Sewage Treatment Plant Operators*, Health Education Service, Albany, N.Y.

The Texas Water Utilities Association, *Manual of Wastewater Operations*, Texas State Department of Health, 1971, Austin, Texas.

U.S. Environmental Protection Agency, *Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities*, Office of Water Program Operations, Publication No. 4301 9-74-002, Washington, D.C.

U.S. Environmental Protection Agency, Technology Transfer, *Handbook for Analytical Quality Control in Water and Wastewater Laboratories*, Analytical Quality Control Laboratory, National Environmental Research Center, Cincinnati, Ohio, June, 1972.

Water Pollution Control Federation, *Simplified Laboratory Procedures for Wastewater Examination*, Publication No. 18, 1971.

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APPENDIX A - OPERATIONAL RECORDS

1.01 INTRODUCTION

Accurate records are the key to consistent process control.

The quantity of records to be kept will depend upon the size and type of the wastewater treatment facility. A small plant may not require the number of variety of records required for a large plant. The specific records required will be determined by the size and number of unit processes within the treatment facility. Generally, these records are categorized as follows:

1) Operational Performance and Process Control
2) Inventory
3) Maintenance
4) O & M Costs
5) Personnel

For the purpose of this manual, only the Operational Performance and Process Control records will be discussed. Several references are listed at the end of this appendix which will provide detailed information concerning other records outlined above. Operational Performance and Process Control records at most wastewater treatment facilities are kept daily and on a monthly basis. Averages for the month of operation are normally recorded on the monthly log.

1.02 OPERATIONAL PERFORMANCE RECORDS

Performance records document the operations and provide the information for process control.

Complete and accurate records of all phases of plant operation and maintenance are essential for the evaluation and control of a biological wastewater treatment facility. Such records are valuable for justifying expenditures, and for making recommendations concerning operational changes, modifications, and expansions. These records are also used to verify compliance with effluent quality requirements. Records should be systematically logged by unit process and filed in a calendar sequence. Generally, the minimum amount of record keeping required includes the following:

1) Daily Log
2) Daily Laboratory Work Sheets
3) Influent and/or effluent flow rates
4) Organic and hydraulic loading rates of each unit process
5) Amount and dosage of chemicals used
6) Power consumption
7) Unusual happenings such as bypasses, floods, storms, complaints, other significant events that could be possibly needed in the future for legal and administrative purposes.

Daily Records

Be sure to enter time of day and initial your entries.

A daily log or diary should be maintained to record events and operations during each shift of plant operation. In larger treatment plants, it may be beneficial to maintain such a log for each unit process. The log may be a standard (8½ x 11) spiral notebook or a standard daily diary made for that purpose.

Daily records are used to observe performance and catalog the day's happenings.

The information entered in the plant log should be pertinent only to plant functions. Log entries must include the time, the day of the week, the date, the year, and the weather conditions. The names of the operators working at the plant, and their arrival and departure times should also be included. Log entries should be made during the day of various activities and problems as they develop. Do not wait until the end of the day to write up the log, as some items may be overlooked. If the operator will take a few minutes to make log entries in the morning and afternoon, he will develop a good log. Logs are beneficial to the operator and to people who replace the operator during vacations, illnesses, or leaves of absence. A well-kept log may prove very helpful to the operating agency as legal evidence in certain cases. An example of one day's log entries in a small trickling filter plant is outlined below:

Tuesday, January 6, 1976 Weather: Clear, Temp. 73° F, Wind-NW

J. Doakes, Operator; A. Smith, Assistant Operator.
G. Doe, Maintenance Helper.

8:20 AM	Made plant checkout, changed flow charts, No. 2 supernatant tube plugged on No. 2 digester, cleared tube.
9:00 AM	Started drawing sludge from bottom of No. 2 digester to No. 1 sand bed.
9:15 AM	Smith and Doe completed daily lubrication and maintenance, put No. 2 filter reciruclation pump on, took No. 1 pump off.
10:00 AM	Received three tons of chlorine, containers Nos. 1583, 1296, 495; returned two empty containers Nos. 1891 and 1344. Replaced bad flex connector on No. 2 chlorine manifold header valve, and connected container No. 495 on standby.
10:30 AM	Collected and analyzed daily lab samples.
1:15 PM	Pumped scum pit, 628 gallons to No. 1 digester.
1:30 PM	Restored sludge pump No. 2 by removing plastic bottle cap from discharge ball check; pump back in operation.
2:45 PM	Smith and Doe hosed down filter distributor arms and cleaned orifices. Doe smashed finger when closing one of the end gates on filter arm. Sent Doe to Dr. Jones, filled out accident report, and notified Mr. Sharp of accident.
3:10 PM	Stopped drawing sludge to No. 1 bed. Drew 18,000 gallons of sludge; sample in refrigerator to be analyzed Wednesday.
3:20 PM	Electrician from Delta Voltage Company in with repaired motor for No. 2 effluent pump, Invoice No. A-1824, motor installed and pump OK.

4:10 PM Doe back from doctor, stated he will lose fingernail, and required three stitches and tetanus shot. Must go back next Thursday.

4:30 PM Plant checkout for tonight, put No. 2 chlorine container on line, in case No. 1 should run empty during the night.

In addition to maintaining a daily log of plant operations daily laboratory data should be kept and transferred to the monthly log form. The daily records should be systematic so that later references can be made. Example daily laboratory worksheets are presented on the following pages.

Monthly Records

Monthly records indicate trends and averages.

Monthly records should report the totals and the averages of the values recorded daily. It is also beneficial to show the maximum and minimum daily results, such as maximum and minimum daily flows.

Daily recorded data are usually transferred onto the monthly data sheets. The monthly data sheet is designed to meet the reporting needs of a particular plant. It should have all important data recorded that may be used later for the preparation of monthly or annual reports.

The monthly data sheet may be a single 8½ x 11 sheet for a small treatment plant, or it may be a number of sheets pertinent to various treatment units within the treatment plant.

How to construct a log.

Normally, every plant operator makes up a monthly data sheet for his plant to record daily information. These sheets are numbered down the left hand side from 1 to 31 to cover the days in the month. Then from left to right across the sheet are columns to record daily information. These columns should contain the day of the week, weather conditions, plant flows, wastewater temperatures, pH, settleable solids, BOD, quantity of sludged pumped, DO, and other pertinent information applicable to various unit processes. A space for remakes is helpful to record and explain unusual events. Typical column headings for an activated sludge plant and trickling filter plant are presented in Figure A-5. Figure A-5 is designed so that it may be composited to fit the needs of a particular plant. Therefore, the operator may develop a monthly log by using Figure A-5 as an example.

Sometimes the operator may use two or three different sheets to collect pertinent data. Since each plant is different, the operator prepares his plant data sheet to record the data he needs to maintain proper plant operation. In addition, he can develop the form to fulfill the requirements of his agency as well as the appropriate regulatory agencies. Generally, these sheets can be classified as an operational performance log and process control log as illustrated in Figure A-5.

In addition to routine daily operation, maintenance, and wastewater characteristics, the monthly data sheet should contain any unusual happenings that may affect interpretation of results and preparation of a monthly report such as unusual weather, floods, bypasses, breakdowns, or changes in operations or maintenance procedures.

B.O.D. WORKSHEET

Date of Sample:__________

Incubation Date In: Date Out:	Primary Standard	Blank Sample			Primary Effluent			Final Effluent		
1. Bottle No.										
2. ml of sample used										
3. Initial D.O.										
4. D.O. after 5 days										
5. D.O. depletion (diff.)										
6. Factor (factor x diff.)										
7. B.O.D. mg/l										
8. Avg. B.O.D. mg/l										

Dilution Water initial D.O. __________

After 5 days incubation __________

Dilution Water D.O. depletion __________

CALCULATIONS:

$$(\text{Initial D.O., mg/l} - \text{D.O. after incubation, mg/l}) \frac{(\text{Bottle capacity, ml})}{(\text{ml of sample used})} = \text{B.O.D., mg/l}$$

FIGURE A-1

C.O.D. WORKSHEET

Date of Sample:__________

Date of Analysis:	Primary Standard	Blank Sample			Primary Effluent			Final Effluent		
1. Reflux Sample No.										
2. ml of sample used										
3. ml FAS for blank										
4. ml FAS for sample										
5. Difference FAS										
6. FAS normality										
7. C.O.D. mg/l										
8. Avg. C.O.D. mg/l										

CALCULATIONS:

$$\frac{(\text{ml FAS blank} - \text{ml FAS sample})}{\text{ml sample use}} \text{ X FAS normality x } 8,000 = \text{COD mg/l}$$

FIGURE A-2

FIGURE A-3

SUSPENDED SOLIDS WORKSHEET

Sample by: ____________________
Date: ____________________
Time: ____________________
Type of Sample: ____________________
Location: ____________________

Analysis by: ____________________
Date: ____________________
Time: ____________________
Method used - Crucible/Filter
(Circle One)

	Run Number			
A	Wt. of crucible/filter, and dry solids, gm			
B	Wt. of crucible/filter, gm			
C	Wt. of dry solids, gm*			
D	ML of sample			
E	Suspended solids, mg/l**	☐	☐	☐

A	Wt. of crucible/ filter, and dry solids, gm			
B	Wt. of crucible/ filter, and ash, gm			
C	Wt. of vol. solids, gm*			
D	ML of sample			
E	Vol. suspended solids, mg/l**	☐	☐	☐

Calculations:

* A - B = C

** $\frac{(C \times 1,000,000)}{D} = E$

FIGURE A-4

DAILY LABORATORY ANALYSIS

30-MINUTE SETTLING TEST

Date

GRAB SAMPLE

Test Set Up: ______________ am

Temp. _____°C

Min.	ML/L
0	____________
5	____________
10	____________
15	____________
20	____________
25	____________
30	____________
40	____________
50	____________
60	____________

SDI or SVI = _______

OBSERVATIONS:

Day

GRAB SAMPLE

Test Set Up: ______________ pm

Temp. _____°C

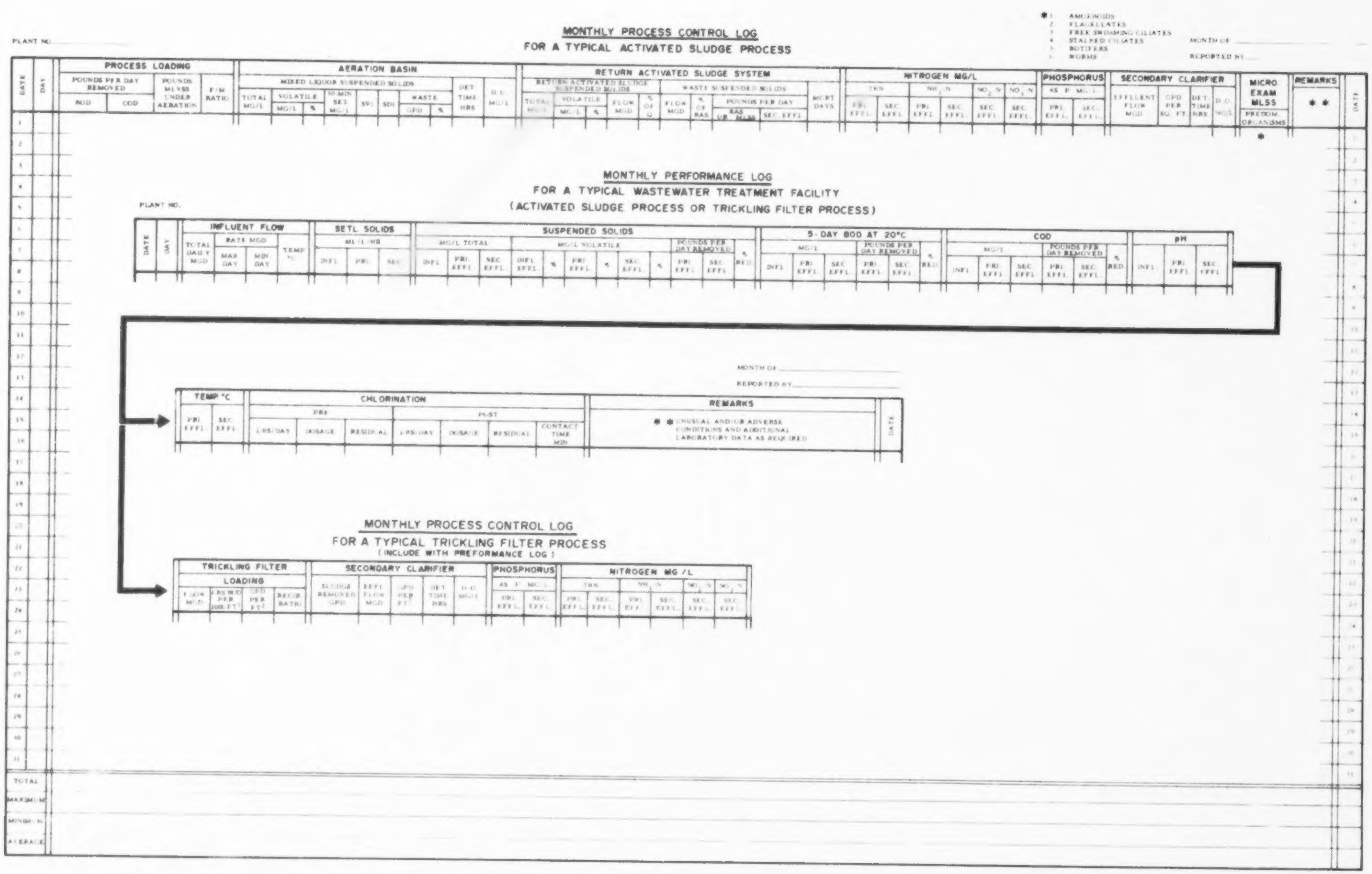
Min.	ML/L
0	____________
5	____________
10	____________
15	____________
20	____________
25	____________
30	____________
40	____________
50	____________
60	____________

SDI or SVI = _______

OBSERVATIONS:

CALCULATIONS:

$$SVI = \frac{30 \text{ min ML/L}}{\text{MLSS mg/l}} \times 1{,}000 \qquad SDI = \frac{100}{SVI}$$



PLANT NO. ______

MONTHLY PROCESS CONTROL LOG

FOR A TYPICAL ACTIVATED SLUDGE PROCESS

* 1 AMOEBOIDS
2 FLAGELLATES
3 FREE SWIMMING CILIATES
4 STALKED CILIATES
5 ROTIFERS
6 WORMS

MONTH OF ______

REPORTED BY ______

DATE	DAY	PROCESS LOADING: POUNDS PER DAY REMOVED: BOD	PROCESS LOADING: POUNDS PER DAY REMOVED: COD	PROCESS LOADING: POUNDS MLVSS UNDER AERATION	PROCESS LOADING: F/M RATIO	AERATION BASIN: MIXED LIQUOR SUSPENDED SOLIDS: TOTAL MG/L	AERATION BASIN: MLSS: VOLATILE MG/L	AERATION BASIN: MLSS: VOLATILE %	AERATION BASIN: MLSS: 30-MIN SET MG/L	AERATION BASIN: MLSS: SVI	AERATION BASIN: MLSS: SDI	AERATION BASIN: MLSS: WASTE GPD	AERATION BASIN: MLSS: WASTE %	AERATION BASIN: DET TIME HRS	AERATION BASIN: D.O. MG/L	RETURN ACTIVATED SLUDGE SYSTEM: RETURN ACTIVATED SLUDGE SUSPENDED SOLIDS: TOTAL MG/L	RAS SS: VOLATILE MG/L	RAS SS: VOLATILE %	RAS SS: FLOW MGD	RAS SS: % OF Q	WASTE SUSPENDED SOLIDS: FLOW MGD	WASTE SS: % OF RAS	WASTE SS: POUNDS PER DAY: RAS OR MLSS	WASTE SS: POUNDS PER DAY: SEC. EFFL	MCRT DAYS	NITROGEN MG/L: TKN: PRI. EFFL.	TKN: SEC. EFFL.	NH3-N: PRI. EFFL.	NH3-N: SEC. EFFL.	NO2-N: SEC. EFFL.	NO3-N: SEC. EFFL.	PHOSPHORUS AS P MG/L: PRI. EFFL.	PHOSPHORUS AS P MG/L: SEC. EFFL.	SECONDARY CLARIFIER: EFFLUENT FLOW MGD	SECONDARY CLARIFIER: GPD PER SQ. FT.	SECONDARY CLARIFIER: DET. TIME HRS	SECONDARY CLARIFIER: D.O. MG/L	MICRO EXAM MLSS: PREDOM. ORGANISMS	REMARKS: * *	DATE
1																																						*		1
2																																								2
3																																								3
4																																								4
5																																								5
6																																								6
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29																																								29
30																																								30
31																																								31
TOTAL																																								
MAXIMUM																																								
MINIMUM																																								
AVERAGE																																								

MONTHLY PERFORMANCE LOG

FOR A TYPICAL WASTEWATER TREATMENT FACILITY

(ACTIVATED SLUDGE PROCESS OR TRICKLING FILTER PROCESS)

PLANT NO.

DATE	DAY	INFLUENT FLOW: TOTAL DAILY MGD	INFLUENT FLOW: RATE MGD: MAX DAY	INFLUENT FLOW: RATE MGD: MIN DAY	INFLUENT FLOW: TEMP °C	SETL SOLIDS ML/L/HR: INFL	SETL SOLIDS ML/L/HR: PRI	SETL SOLIDS ML/L/HR: SEC	SUSPENDED SOLIDS: MG/L TOTAL: INFL	MG/L TOTAL: PRI. EFFL	MG/L TOTAL: SEC EFFL	MG/L VOLATILE: INFL EFFL	%	MG/L VOLATILE: PRI EFFL	%	MG/L VOLATILE: SEC EFFL	%	POUNDS PER DAY REMOVED: PRI EFFL	POUNDS PER DAY REMOVED: SEC EFFL	% RED	5-DAY BOD AT 20°C: MG/L: INFL	MG/L: PRI. EFFL	MG/L: SEC. EFFL	POUNDS PER DAY REMOVED: PRI. EFFL	POUNDS PER DAY REMOVED: SEC. EFFL	% RED	COD: MG/L: INFL	MG/L: PRI EFFL	MG/L: SEC EFFL	POUNDS PER DAY REMOVED: PRI EFFL	POUNDS PER DAY REMOVED: SEC. EFFL	% RED.	pH: INFL	pH: PRI EFFL	pH: SEC EFFL

MONTH OF ______

REPORTED BY ______

TEMP °C: PRI. EFFL.	TEMP °C: SEC. EFFL.	CHLORINATION: PRE: LBS/DAY	PRE: DOSAGE	PRE: RESIDUAL	POST: LBS/DAY	POST: DOSAGE	POST: RESIDUAL	POST: CONTACT TIME MIN	REMARKS: * * UNUSUAL AND/OR ADVERSE CONDITIONS AND ADDITIONAL LABORATORY DATA AS REQUIRED	DATE

MONTHLY PROCESS CONTROL LOG

FOR A TYPICAL TRICKLING FILTER PROCESS

(INCLUDE WITH PREFORMANCE LOG)

TRICKLING FILTER: LOADING: FLOW MGD	LOADING: LBS BOD PER 1000 FT³	LOADING: GPD PER FT²	LOADING: RECIR. RATIO	SECONDARY CLARIFIER: SLUDGE REMOVED GPD	SECONDARY CLARIFIER: EFFL FLOW MGD	SECONDARY CLARIFIER: GPD PER FT²	SECONDARY CLARIFIER: DET TIME HRS	SECONDARY CLARIFIER: D.O. MG/L	PHOSPHORUS AS P MG/L: PRI. EFFL.	PHOSPHORUS AS P MG/L: SEC. EFFL.	NITROGEN MG/L: TKN: PRI. EFFL.	TKN: SEC. EFFL.	NH3-N: PRI. EFF.	NH3-N: SEC. EFFL.	NO2-N: SEC. EFFL.	NO3-N: SEC. EFFL.

MONTHLY PROCESS CONTROL AND PREFORMANCE LOGS

FIGURE A-5

1.03 COMPUTER AIDED DATA MANAGEMENT

An important new tool.

The computer is an economical aid for data collection and analysis. The computer can be used to tabulate and analyze all of the data needed to perform routine and non-routine process control operations. The computer can also be used to inventory equipment, to log maintenance requirements, and to provide completed report forms for regulatory agencies.

Low cost data processing.

Typical operations costs for process control data management would be less than $250 per month. These costs include terminal rental and computer time. A nominal initial cost would be involved to generate the programs used for a particular treatment plant.

A good reference.

A recent article* described the operation of a computer program used to tabulate and analyze the operating data needed to monitor the operation of an activated sludge plant. Table A-1 (from the article) presents the minimum data required to properly operate and monitor an activated sludge treatment plant. Note that the data are tabulated on a daily basis, although process control is based upon averaged data.

Note the format in Table A-1.

The data format used in Table A-1 makes the data easily usable. It is strongly recommended that the data shown on Table A-1 be tabulated in this format, because of the general usefulness of these data in treatment plant operations. These fifteen data entries can be used as a starting point for the proper operation and monitoring of any plant.

The computer can fill in performance.

Reports to regulatory agencies.

Additional use of the computer include the generation of monthly performance reports to regulatory agencies, and cataloging maintenance operations and equipment inventory. The computer can be used to prompt or remind operations personnel that scheduled maintenance operations are due. The computer can continue to catalog outstanding maintenance operations until the operator responds with a signal that the duty is completed.

Easily used tool.

The computer is an easily used tool that can be programmed to perform routine data tabulation and analysis. With minimal effort, operations personnel can readily learn to use and depend on the computer, freeing their time to perform other necessary functions.

*Trussel, R., et al., "Computer Assisted Operation of an Activated Sludge Plant", October, 1974.

1.04 INTERPRETATION OF RECORDS

Interpretation— The main purpose of keeping records.

Records are not useful unless they are evaluated and used as indicators of plant operation and maintenance. Records are also useful as sources for reports to management or the public.

Use your records frequently.

The recorded data can enable the operator to determine operation and maintenance needs of his plant. The information shown by the records should also indicate to him and to his supervisor the treatment efficiency of each unit in the plant. Records kept on the quality of the effluent and the receiving waters should be analyzed for the discharge's effect on the receiving waters. The importance of looking at and analyzing records frequently cannot be overemphasized.

TABLE A-1

WEEKLY REPORT OF PROCESS PARAMETERS
WEEK ENDING 10/2/74

DATE	LOADING				
	FLOW MGD	COD MG/L	COD LBS	SS MG/L	SS LBS
9/26	2.73	349.	7946.	158.	3597.
9/27	2.68	434.	9700.	148.	3308.
9/28	2.70	434.	9773.	455.	10246.
9/29	2.85	434.	10334.	102.	2429.
9/30	2.80	357.	8337.	112.	2615.
10/ 1	2.96	374.	9242.	108.	2669.
10/ 2	2.74	376.	8598.	127.	2904.
AVG	2.78	394.	9133.	173.	3967.

DATE	CONTROL				
	F/M	SRT DAYS	SOLIDS LBS	SETT'LY %	SVI ML/GM
9/26	0.40	20.2	19996.	51.0	225.
9/27	0.50	86.9	19433.	36.0	168.
9/28	0.97	37.3	10088.	32.0	192.
9/29	0.94	24.2	10970.	30.0	169.
9/30	0.41	78.2	20184.	59.0	173.
10/ 1	0.51	51.4	17947.	82.0	270.
10/ 2	0.78	36.9	10966.	37.0	198.
AVG	0.65	47.9	15655.	46.7	199.

DATE	PERFORMANCE				
	TURBIDITY	SS MG/L	SS % REMOVED	COD MG/L	COD % REMOVED
9/26	2.7	14.0	91.1	47.	86.5
9/27	3.3	11.0	92.6	54.	87.6
9/28	5.4	12.0	97.4	54.	87.6
9/29	5.6	23.0	77.5	54.	87.6
9/30	5.6	16.0	85.7	78.	78.2
10/ 1	5.6	19.0	82.4	48.	87.2
10/ 2	6.1	18.0	85.8	58.	84.6
AVG	4.9	16.1	87.5	56.	85.6

Laboratory analyses performed on various samples provide essential tools to aid in the control and evaluation of a biological treatment process. Table A-2 presents a list of the analyses and their use in performance evaluation and process control.

Look for trends.

Records should not only be analyzed as a single piece of data, but any variation should be looked upon for its relation to another source of data. For example, a sudden rise in temperature of the influent might be accompanied by greatly increased flows. This could indicate a large industrial discharge. This discharge could also influence the BOD and suspended solids concentrations in the plant influent. Or one might observe a sudden increase in 5-day BOD concentrations in the plant effluent. This may indicate a seasonal increase due to beginning of cannery operations, or it may indicate a breakdown of industrial treatment facilities discharging untreated wastes into the wastewater collection system.

Look for sudden variations.

Before any meaningful interpretation can be made of sudden variations in data, an expected range of values has to be determined for the particular treatment unit under consideration. This range must be based upon expected or past performance. For example, if average daily flows during weekdays were around two million gallons per day and suddenly a flow of 0.5 million gallons per day was recorded, this may indicate malfunctioning of metering equipment or a break in sewer lines or a bypass ahead of the plant. Conversely, unusually high flows may indicate storm water infiltration, surface water runoff flowing into the system through manholes, or an unusual dump of wastewater.

An excellent way to facilitate review of daily records and detect sudden changes or trends are prepared charts showing values plotted against days or time. Unless results are plotted, slight changes and trends can go undetected. The deviation from the expected values may have been caused by unusual circumstances or an error in observation or analysis.

Trend Plots

Plotting your data increases in value.

Plotting data on graphs is very helpful to illustrate trends in the operation of a wastewater treatment facility. Regular plotting of data may reveal unexpected trends which could provide insight to prevent an operational upset of a unit process. In addition, this approach could be utilized to justify budget requirements, and to show the need for plant modifications or expansion. To look for or show a trend, plot the value or values against time as illustrated in Figure A-6. The important concepts relevant to plotting trend charts are discussed below:

Use of average data.

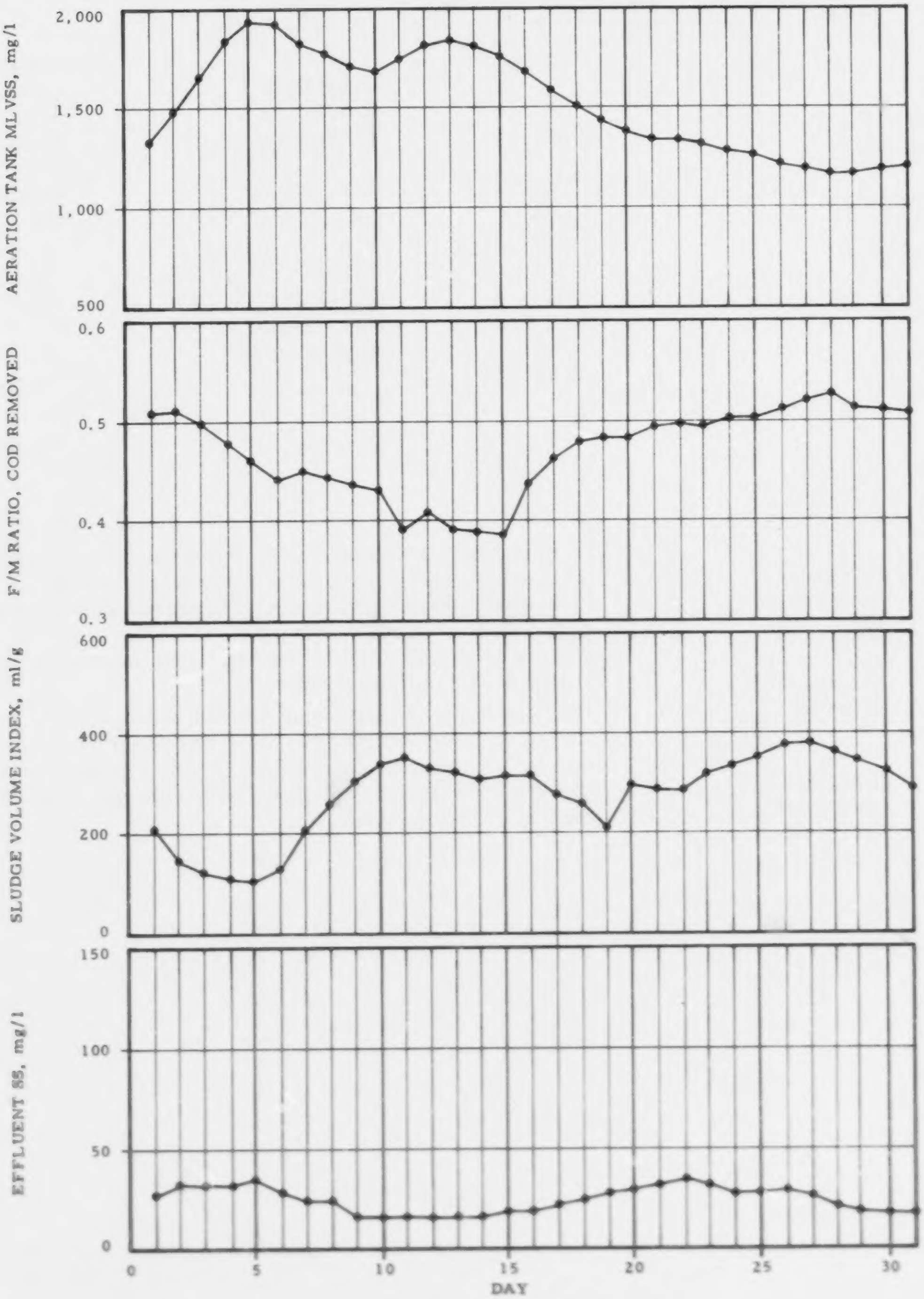
1. Plotting daily data will not provide good process control interprettions. A 5-day moving average method is suggested for normal operations. In cases where data is not taken daily, the collected data can still be used to generate moving averages. Each day a new set of data is included and one data set is deleted from the group of five to be averaged.

TABLE A-2

SUMMARY OF LABORATORY CONTROL TEST APPLICATIONS FOR PROCESS CONTROL AND PERFORMANCE EVALUATION

<table>
<tr><th>TEST/SAMPLE</th><th>ACTIVATED SLUDGE PROCESS</th><th>TRICKLING FILTER PROCESS</th></tr>
<tr><td rowspan="2">BOD - COD
PRIMARY EFFLUENT
SECONDARY EFFLUENT</td><td colspan="2">● ORGANIC LOAD APPLIED
● ORGANIC LOAD REMOVED
● EVALUATE PROCESS PERFORMANCE</td></tr>
<tr><td>○ MCRT DETERMINATIONS
○ F/M RATIO DETERMINATIONS</td><td>○ RECIRCULATION RATE REQUIREMENTS</td></tr>
<tr><td rowspan="2">SUSPENDED SOLIDS
TOTAL
PRIMARY EFFLUENT
MIXED LIQUOR
FILTER EFFLUENT
SECONDARY EFFLUENT
RAS/WAS
VOLATILE
PRIMARY EFFLUENT
MIXED LIQUOR
SECONDARY EFFLUENT
RAS/WAS</td><td colspan="2">● ORGANIC LOAD APPLIED
● ORGANIC LOAD REMOVED
● EVALUATE PROCESS PERFORMANCE
● SOLIDS LOADING ON SECONDARY CLARIFIER
● MASS BALANCE DETERMINATIONS</td></tr>
<tr><td>○ RAS/WAS RATES
○ MLVSS LEVELS IN AERATION BASIN
○ MCRT DETERMINATIONS</td><td>○ SLUDGE REMOVAL RATES FROM CLARIFIER</td></tr>
<tr><td>NITROGEN-KJEDAHL
PRIMARY EFFLUENT
SECONDARY EFFLUENT
AMMONIA
PRIMARY EFFLUENT
SECONDARY EFFLUENT
NITRITE
PRIMARY EFFLUENT
SECONDARY EFFLUENT
NITRATE
PRIMARY EFFLUENT
SECONDARY EFFLUENT
PHOSPHORUS
PRIMARY EFFLUENT
SECONDARY EFFLUENT</td><td colspan="2">● NITRIFICATION
● NUTRIENT BALANCE</td></tr>
<tr><td>30-MINUTE SETTLING
MIXED LIQUOR</td><td>○ SLUDGE QUALITY AND SETTLING CHARACTERISTICS
○ SVI
○ SDI
○ SLUDGE REMOVAL RELATIVE TO DENITRIFICATION</td><td></td></tr>
<tr><td rowspan="2">DO
RAW WASTEWATER
MIXED LIQUOR
SECONDARY EFFLUENT</td><td colspan="2">● TOXIC SHOCK LOAD
● OXYGEN DEMAND FOR CHANGES IN ORGANIC LOADING
● OXYGEN TRANSFER EFFICIENCY</td></tr>
<tr><td>○ AERATION REQUIREMENTS</td><td>○ RECIRCULATION RATE REQUIREMENTS</td></tr>
<tr><td>pH
PRIMARY EFFLUENT
MIXED LIQUOR
SECONDARY EFFLUENT
TEMPERATURE
PRIMARY EFFLUENT
MIXED LIQUOR
SECONDARY EFFLUENT</td><td colspan="2">● SURVEILLANCE OF ILLEGAL INDUSTRIAL WASTE DISCHARGES ADVERSE TO BIOLOGICAL SYSTEM
● DETECTION OF INFILTRATION-INFLOW
● REFLECTS CONDITION OF BIOLOGICAL ACTIVITY
● REFLECTS CONDITIONS OF NITRIFICATION</td></tr>
<tr><td rowspan="2">SETTLEABLE SOLIDS
PRIMARY EFFLUENT
FILTER EFFLUENT
SECONDARY EFFLUENT</td><td colspan="2">● EFFICIENCY OF CLARIFIER</td></tr>
<tr><td></td><td>○ SLUDGE REMOVAL RATES FROM CLARIFIER</td></tr>
<tr><td>MICROSCOPIC EXAMINATION
MIXED LIQUOR</td><td>○ ASSIST IN MCRT DETERMINATIONS
○ RELATIVE PREDOMINANCE OF MICROORGANISMS
○ OPERATIONAL PROBLEMS RELATIVE TO FILAMENTOUS ORGANISMS
○ EVALUATE SLUDGE QUALITY</td><td></td></tr>
<tr><td>FLOW</td><td colspan="2">● DETERMINE APPLIED LOADS
● HYDRAULIC DETENTION TIME</td></tr>
<tr><td>SLUDGE BLANKET
SECONDARY CLARIFIER</td><td>○ SOLIDS DISTRIBUTION
○ USE TO DETERMINE RAS FLOW RATES
○ EVALUATE HYDRAULICS</td><td></td></tr>
</table>

● APPLICABLE TO BOTH BIOLOGICAL PROCESSES



ACTIVATED SLUDGE PROCESS
(Five-day moving average trend plots)

FIGURE A-6

How to generate a 5-day moving average.

For example, 5-day moving averages for a 2-day period (January 5 and 6, 1976) are calculated as follows:

Date	Initial Data Group BOD mg/l		Sequential Data Group BOD mg/l
1-1-76	120		Deleted
1-2-76	118		118
1-3-76	124		124
1-4-76	122		122
1-5-76	121		121
Total	605 ÷ 5 = 121 avg. for 1-5-76		
1-6-76			123 added
		Total	608 ÷ 5 = 122 avg. for 1-6-76

Plot process control data:
F/M
MCRT
MLVSS
Effluent SS
Effluent BOD
Etc.

Learn to plot accurately and meaningfuly.

2) All data used for process control should be plotted on a daily, weekly, and monthly basis. Daily plots showing large variations indicate that either shock loadings or errors in operation and/or calculation have occurred. Weekly and monthly plots will show long-term changes and indicate whether the control exerted by the process control techniques is suited to operating conditions.

3) The operator must familiarize himself with the techniques of graphically displaying data, in order to get the maximum amount of information out of the data. Trend observation is probably the singlemost important tool that the operator has to prevent catastrophic upset of the biological processes.

REFERENCES

New York State Department of Health, *Laboratory Procedures for Wastewater Treatment Plant Operators,* Health Education Service, Albany, N.Y.

New York State Department of Health, *Manual of Instruction for Sewage Treatment Plant Operators,* Health Education Service, Albany, N.Y.

Recommended Standards for Sewage Works, 1973 Revised Edition, Published by Health Education Service, Albany, N.Y.

Sacramento State University, *Operation of Wastewater Treatment Plants - A Field Study Program,* Sacramento, California.

Texas Water Utilities Association, *Manual of Wastewater Operations,* Texas State Department of Health, 1971, Austin, Texas.

Trussell, R.R., Bravo, A., Kermit, P., and Nichels, C., *Computer Assisted Operation of an Activated Sludge Plant,* Presented at the 47th Annual Convention of the Water Pollution Control Federation, October, 1974.

APPENDIX B - PLANT VISTS

The wastewater treatment plants included in this appendix were visited to establish the state-of-the-art for process control of aerobic biological wastewater treatment facilities throughout the United States.

A statistical breakdown of the types and methods of operation for each plant visit is included.

CITY OF AMARILLO, TEXAS

General Description

The River Road Wastewater Treatment Plant consists of screening, primary sedimentation, primary effluent holding pond (balancing), secondary treatment by the activated sludge process, and post chlorination. The activated sludge process has the flexibility of operating in the following modes: (1) conventional, (2) step-feed or variations therein: reaction, contact stabilization and Kraus. Currently, the reaction mode is used throughout the year.

Performance and Process Control

They have the flexibility of wasting activated sludge by wasting from the return sludge flow and/or wasting mixed liquor from the channel conveying the aeration effluent to the secondary clarifiers. They utilize both wasting modes simutaneously. The waste RAS is returned to the plant influent for sedimentation with the primary sludge. The mixture of primary sludge and waste RAS is pumped to a gravity thickener. The RAS wasting rate remains at a fairly constant rate (the rate is based upon achieving the desired effect in the primary sludge thickener) while mixed liquor wasting rate is varied as needs dictate. The digester sludge is pumped to clay-bottom drying beds with the decant liquor returned to the plant influent.

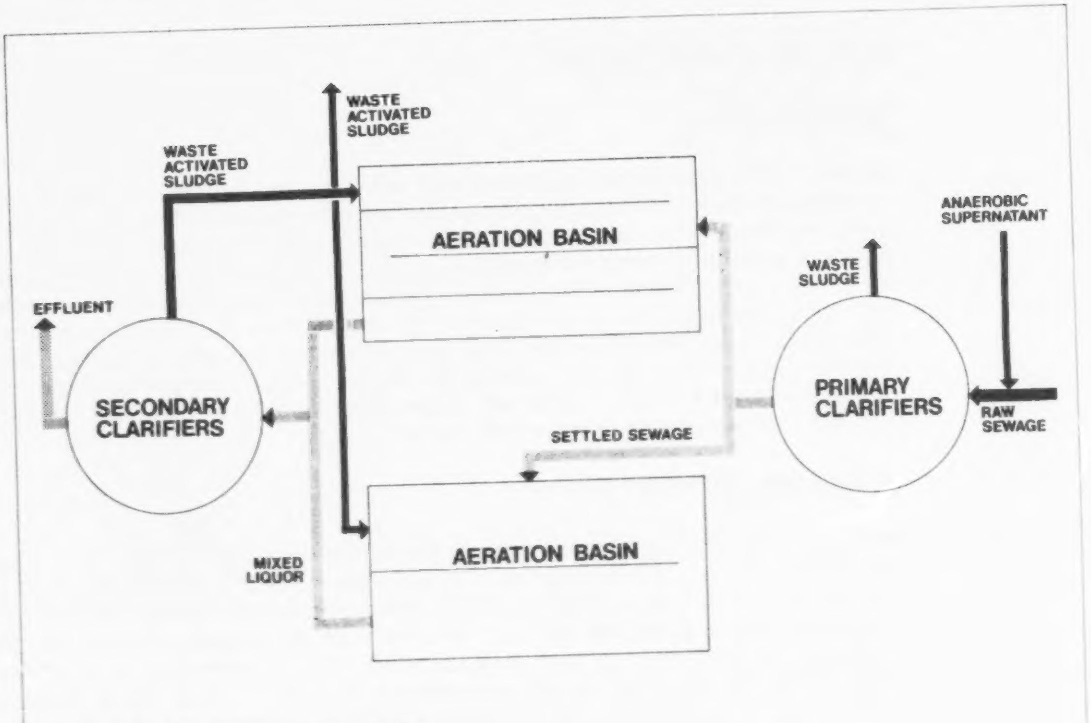
In order to balance the wastewater flows to the secondary treatment process, the plant personnel constructed an earthen primary effluent holding pond. It should be noted that this wastewater treatment facility is situated in the country with no nearby neighbors to complain about the odors or appearance. This type of flow balancing has been effective and quite satisfactory.

The plant utilized the conventional mode of the activated sludge process prior to the City obtaining a new source of water supply from a lake. The lake water possesses a high sulfate and chloride content with wide swings in the water temperature throughout the year. After the lake water was used as the City's water source, the plant began to experience severe bulking problems (probably due to high sulfates and swings in wastewater [55 - 80° F] temperature). The sludge reaeration mode of operation was tried with three hours in the reaeration zone and three hours in the aeration zone. They concluded that the reaeration mode was effective in minimizing their bulking problems. They now use the reaeration mode throughout the year.

The WAS rates are based upon the maintenance of a constant MLSS concentration. Response of the process and past experience are basically the guides used to increasing or decreasing the MLSS level. This procedure seems to work quite satisfactorily in conjunction with the balancing of the primary effluent flow.

The RAS rate was adjusted upon the basis of a daily sludge blanket depth measurement. An electronic sludge blanket detector is utilized to measure the sludge depth in the clarifier.

DO's of 2-3 mg/l are maintained at the outlet of aeration basins. DO's greater than 3.5 mg/l are avoided because filamentous organism tend to predominate in the activated sludge.


WASTE
ACTIVATED
SLUDGE
WASTE
ACTIVATED
SLUDGE
AERATION BASIN
ANAEROBIC
SUPERNATANT
WASTE
SLUDGE
EFFLUENT
SECONDARY
CLARIFIERS
PRIMARY
CLARIFIERS
RAW
SEWAGE
SETTLED SEWAGE
MIXED
LIQUOR
AERATION BASIN

PLANT FLOW DIAGRAM

```
                 CITY OF AMARILLO, TEXAS    RIVER ROAD PLANT
                        CONVETIONAL ACTIVATED SLUDGE
                      CURRENT PLANT IN OPERATION - 1968

                                                          PLANT DESIGN
           PLANT FLOW

                   DESIGN       TYPICAL          AERATION BASINS              CLARIFIERS

                                                                              NUMBER               4
  AVG DRY WEATHER,MGD   12.0      10.9           NUMBER            2          DIAMETER,FT         75.
  MAX DAY,MGD           14.2      14.2           LENGTH,FT         0.         DEPTH,FT            10.5
  PEAK HOUR,MGD         22.0      22.0           WIDTH,FT          0.         AREA-EACH,SF      4418.
  % INDUSTRIAL -                  10.            DEPTH,FT          0.         WEIR LENGTH,FT     430.
                                                 AREA-EACH,SF      0.         WEIR TYPE      V-NOTCH
                                                                              SLUDGE REMOVAL     PLOW
           PLANT LOADING                         AERATION SYSTEM

 AERATION BASINS                 DESIGN      TYPICAL      SYSTEM       DIFFUSED
                                                          TYPE          SPARGER
   INF BOD5,MG/L                  120.        120.        MAX SCFM     14000.
   INF SS,MG/L                     80.         80.        AVG SCFM     11000.
   F/M,LB BOD5 REM/LB MLVSS/DAY     0.25        0.24
   MCRT,DAYS                        3.5         3.3
   SLUDGE AGE,DAYS                  3.0         4.1
   MLSS,MG/L                     2000.       2000.
   MAX MLSS,MG/L                             2400.
   MIN MLSS,MG/L                             1500.                     PLANT PERFORMANCE
   % VOLATILE                                  80.
   D.O. LEVELS,MG/L                 2.0         2.0                               DESIGN     TYPICAL
   AIR APPLIED,SCF/GAL                          1.5
   AIR APPLIED,SCF/LB BOD5 REM               1809.            EFF BOD5,MG/L        15.0       15.0
   RETURN, %                       80.         80.            % BOD5 REMOVAL       88.        88.
   MAX RETURN, %                   36.                        EFF SS,MG/L          10.0       10.0
   DET. TIME,@ AVG FLOW,HOURS       6.0         5.6           % SS REMOVAL         84.        83.
   DET. TIME,@ A.F.+RETURN,HOURS    3.4         4.1           SVI,ML/GRAM                    200.
   DET. TIME,@ M.F.+RETURN,HOURS    3.5         3.5           SDI,GRAM/100ML                   0.50


                                        DESIGN                   TYPICAL
 SECONDARY CLARIFIERS            MAX DAY       AVG        MAX DAY        AVG

   SURFACE LOADING,GAL/SF/DAY     804.        679.         804.         617.
   WEIR LOADING,GAL/FT/DAY       8256.       6977.        8256.        6337.
   DETENTION TIME,HOURS             2.3         2.8          2.3          3.3
   SOLIDS LOADING,LBS/SF/HOUR       0.80        0.73         0.80         0.88
```

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CITY OF AUSTIN, TEXAS

General Description

At the Govalle Wastewater Treatment Plant there are four activated sludge plants fed from a common influent diversion structure. The accumulated data only pertain to "D" plant, the newest and most modern. The splitting of the influent flows to A, B, C, and D plants is accomplished by motorized sluice gate valves at the influent diversion structure. The contact stabilization mode of the activated sludge process preceded by screening and grit removal is utilized at "D" plant. There are three feed points into the aeration basin which function as a means to control the detention time in contact zone. They attempt to maintain a detention time of 20-30 minutes in the contact zone. The operator claims that a sludge with optimum settling characteristics is attained by a contact detention time of approximately 30 minutes.

Performance and Process Control

Excess activated sludge is wasted from the stabilization zone (sludge reaeration) of the aeration basin and discharged to an aerobic digester with a one-day detention time. The digester liquor is transferred to 191 acres of oxidation ponds. Except for the underflow from the chlorine contact tank, there are no recycled flows at "D" plant. They vary the WAS rates to maintain a suspended solids concentration in the RAS of 3,500-5,000 mg/l. They would also increase the WAS rate if they had an increase in sludge blanket depth without an increase in SVI. The suspended solids concentration of the return sludge governs the suspended solids concentration in the stabilization zone. They use the following ratio to indicate if they need to increase or decrease WAS rate:

$$\frac{\text{BOD of return sludge, mg/l}}{\text{Suspended Solids of return sludge, mg/l}} = 50.5 \text{ to } 0.7$$

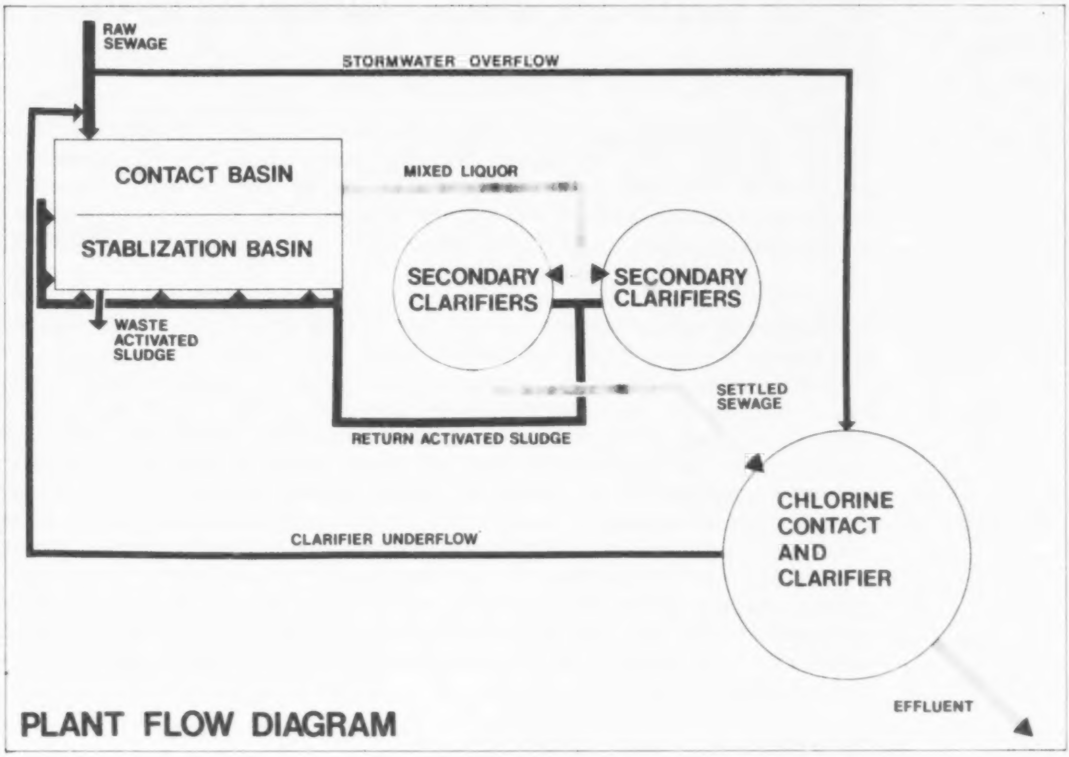
The above ratio would seem to indicate the degree of stabilization, which in turn is related to the sludge age and F/M ratio.

The RAS rates are adjusted to maintain the desired suspended solids concentration (stabilization zone) while maintaining less than two feet of sludge blanket in the secondary clarifiers. Small air lifts installed in the clarifiers at fixed two-foot intervals indicate sludge blanket depth.

They maintain a DO of 1 to 2 mg/l at the outlet of the aeration basin. Aeration rates also are controlled to maintain a DO of 0.5 mg/l in the secondary clarifiers just prior to the effluent weir to avoid septicity in the return sludge.

Wastewater temperature is as high as 84° F in the summer and as low as 69° F in the winter. In the winter, they increase the suspended solids level to compensate for slower biological activity. Also, they decrease the air rates to avoid excessive DO's and subsequent filamentous organism growth.

Storm flows are diverted around the activated sludge processes through a bar screen to a storm overflow clarifier, chlorinated and discharged to the outfall. The underflow from the clarifier is pumped to the influent diversion structure. The storm overflow clarifier also serves as the chlorine contact tank for "D" plant.


RAW SEWAGE
STORMWATER OVERFLOW
CONTACT BASIN
STABLIZATION BASIN
MIXED LIQUOR
SECONDARY CLARIFIERS
SECONDARY CLARIFIERS
WASTE ACTIVATED SLUDGE
SETTLED SEWAGE
RETURN ACTIVATED SLUDGE
CHLORINE CONTACT AND CLARIFIER
CLARIFIER UNDERFLOW
EFFLUENT

PLANT FLOW DIAGRAM

```
                         CITY OF AUSTIN, TEXAS - GOVALLE PLANT
                               CONTACT STABILIZATION
                          CURRENT PLANT IN OPERATION - 1971

                PLANT FLOW                                        PLANT DESIGN

                          DESIGN        TYPICAL       AERATION BASINS          CLARIFIERS

    AVG DRY WEATHER,MGD    10.0           9.0         NUMBER             1     NUMBER              2
    MAX DAY,MGD            15.0          15.0         LENGTH,FT       150.     DIAMETER,FT      110.
    PEAK HOUR,MGD          15.0          15.0         WIDTH,FT         90.     DEPTH,FT         12.0
    % INDUSTRIAL                         10.          DEPTH,FT         15.     AREA-EACH,SF    9503.
                                                      AREA-EACH,SF  13500.     WEIR LENGTH,FT   650.
                                                                               WEIR TYPE     V-NOTCH
                PLANT LOADING                         AERATION SYSTEM          SLUDGE REMOVAL   PLOW

  AERATION BASINS                  DESIGN       TYPICAL     SYSTEM      DIFFUSED
                                                            TYPE         SPARGER
    INF BOD5,MG/L                   180.         160.       MAX SCFM    17700.
    INF SS,MG/L                     180.         160.       AVG SCFM    11800.
    F/M,LB BOD5 REM/LB MLVSS/DAY     0.75         0.55
    MCRT,DAYS                       12.0         18.0
    SLUDGE AGE,DAYS                  5.5          2.1
    MLSS,MG/L                      2500.        2000.
    MAX MLSS,MG/L                               2300.
    MIN MLSS,MG/L                               1500.
    % VOLATILE                                    80.                    PLANT PERFORMANCE
    D.O. LEVELS,MG/L                 1.5          1.5
    AIR APPLIED,SCF/GAL                           2.                        DESIGN     TYPICAL
    AIR APPLIED,SCF/LB BOD5 REM                 1540.
    RETURN, %                       44.           44.         EFF BOD5,MG/L         20.0       13.0
    MAX RETURN, %                   67.                       % BOD5 REMOVAL        89.        92.
    DET. TIME,# AVG FLOW,HOURS       3.6          4.0         EFF SS,MG/L           20.0       14.0
    DET. TIME,# A.F.+RETURN,HOURS    2.6          2.8         % SS REMOVAL          89.        91.
    DET. TIME,# M.F.+RETURN,HOURS    1.9          1.9         SVI,ML/GRAM                     110.
                                                              SDI,GRAM/100ML                    0.91

  SECONDARY CLARIFIERS               DESIGN                 TYPICAL
                              MAX DAY       AVG       MAX DAY       AVG

    SURFACE LOADING,GAL/SF/DAY    789.        526.        789.        474.
    WEIR LOADING,GAL/FT/DAY     11538.       7692.      11538.       6923.
    DETENTION TIME,HOURS            2.7         4.1         2.7         4.5
    SOLIDS LOADING,LBS/SF/HOUR      0.87        0.64        0.89        0.48
```

CITY OF CARSON CITY, NEVADA - WASTEWATER TREATMENT PLANT

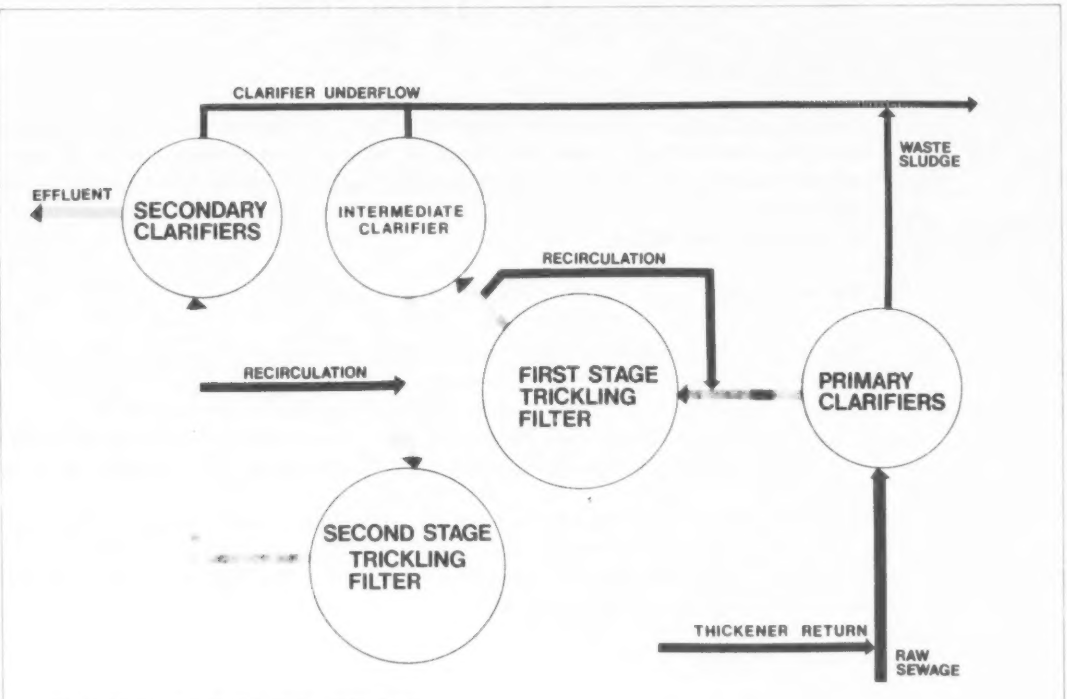
General Description

The Carson City Wastewater Treatment Plant is a two-stage trickling filter plant with a design capacity of 3.75 mgd ADWF. The plant was originally put into operation in 1961 as a primary treatment facility with 1.5 mgd design flow capacity, expanded to the secondary treatment (as the same design flow) in 1968. and expanded to the current design flow capacity in 1974. The current ADWF at the plant is approximately 2.1 mgd.

The principal unit processes of the plant are as follows: comminution grit removal via a grit cyclone, primary sedimentation, flow measurement with Parshall flumes a primary stage trickling filter, intermediate clarification (with recirculation of the intermediate clarifier overflow to the primary trickling filter), a second stage trickling filter (with recirculation of unsettled effluent), final clarification, chlorination, and effluent disposal. Primary and secondary sludges are thickened, centrifuged, and incinerated at on-site facilities. Centrate is returned to the thickener, and thickener overflow is returned to the primary sedimentation basins. Effluent disposal is either to the Carson River or to reclamation at a nearby golf course. In either case, the effluent is held in an effluent storage pond prior to disposal. Excess flow to the plant during storms is bypassed from a manhole prior to the plant headworks and from the wet well of the primary stage trickling filter feed pumps to an oxidation pond. This stored overflow is recycled back to the plant headworks during dry weather for retreatment. Additionally, some excess stormwater can be bypassed around the primary stage trickling filter to the secondary stage trickling filter.

Performance and Process Control

The treatment plant operator has no control over the mode or rate of recirculation around either trickling filter stage. In both cases, recirculated flow is returned to the wet wells of the filter feed pumps by gravity flow. The water level in these wet wells are in turn controlled by level-actuated constant speed pumps. This method of recirculation results in a relatively constant hydraulic loading rate to each filter. However, the organic loading rate to each filter is highly dependent on the hydraulic influent flow rate to the plant.


CLARIFIER UNDERFLOW
WASTE SLUDGE
EFFLUENT
SECONDARY CLARIFIERS
INTERMEDIATE CLARIFIER
RECIRCULATION
FIRST STAGE TRICKLING FILTER
PRIMARY CLARIFIERS
RECIRCULATION
SECOND STAGE TRICKLING FILTER
THICKENER RETURN
RAW SEWAGE

PLANT FLOW DIAGRAM

```
                         CARSON CITY, NEVADA
                      HIGH RATE TRICKLING FILTER
                   CURRENT PLANT IN OPERATION - 1968

        PLANT FLOW                                      PLANT DESIGN

                       DESIGN      TYPICAL      TRICKLING FILTERS          CLARIFIERS

   AVG DRY WEATHER,MGD   3.7         3.0        NUMBER             2       NUMBER              2
   MAX DAY,MGD           7.5         4.0        DIAMETER,FT       80.      DIAMETER,FT        75.
   PEAK HOUR,MGD         7.5         4.4        DEPTH,FT           7.0     DEPTH,FT           12.0
   % INDUSTRIAL                      0.         AREA-EACH,SF    5027.      AREA-EACH,SF     4418.
                                                VOL-EACH,CF    35186.      WEIR LENGTH,FT    250.
                                                                           WEIR TYPE      V-NOTCH
                                                                           SLUDGE REMOVAL    PLOW


        PLANT LOADING                                   PLANT PERFORMANCE

 TRICKLING FILTERS                DESIGN      TYPICAL                        DESIGN     TYPICAL

   INF BOD5,MG/L                   175.        140.      EFF BOD5,MG/L        24.0       30.0
   INF SS,MG/L                     175.        140.      % BOD5 REMOVAL       86.        79.
   ORG LOAD,LBBOD5/1000CF/DAY       77.         50.      EFF SS,MG/L          24.0       20.0
   HYD LOAD, MGD/ACRE               48.         39.      % SS REMOVAL         85.        86.
   RECIRCULATION,%                  50.         50.


 SECONDARY CLARIFIERS                  DESIGN               TYPICAL
                                  MAX DAY     AVG      MAX DAY     AVG

   SURFACE LOADING,GAL/SF/DAY      1698.      849.       905.      679.
   WEIR LOADING,GAL/FT/DAY        30000.    15000.     16000.    12000.
   DETENTION TIME,HOURS               1.3       2.5        2.4       3.2
```

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CITY OF DALLAS, TEXAS - CENTRAL PLANT

General Description

The Dallas Central Wastewater Treatment Plant consists of two trickling filter plants—the older Dallas Wastewater Treatment Plant with single stage standard rate T.F., and the White Rock Wastewater Treatment Plant with roughing T.F. followed by high-rate T.F. At both plants, the trickling filters are preceded by screening, grit removal, and primary sedimentation.

Performance

The sludge from the final clarifiers is returned to the plant influent for sedimentation with the primary sludge. The control of sludge withdrawal rates from the final clarifier is determined by visual observation. The mixture of primary and trickling filter sludge is pumped to anaerobic digesters for stabilization. The digester liquor is transferred to another plant for disposal, thus there is no supernatant recycle flows at these plants.

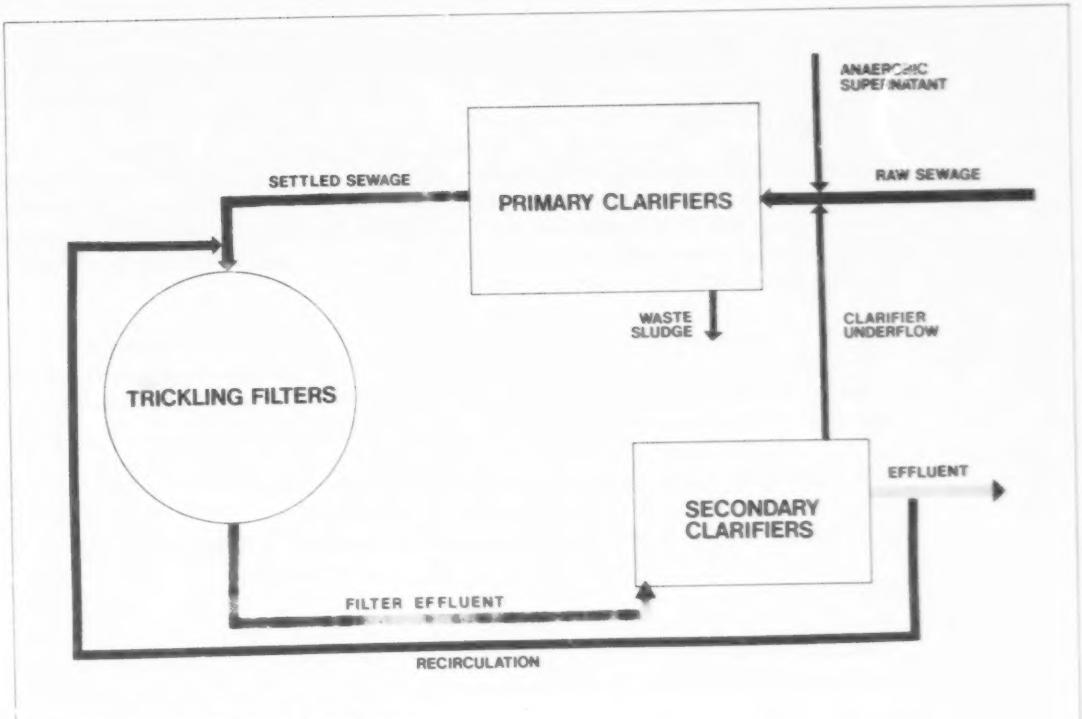
At both plants, final clarifier effluent is returned to the trickling filters to provide continuous dosing and reasonably constant hydraulic loading. The recirculation rates are based on maintenance of a specific total flow to the trickling filters. This procedure seems to be simple and effective.

Process Control

They performed an extensive lab monitoring program; however, the lab results are not primarily for trickling filter process control. Process control is based on maintaining a constant hydraulic loading via recirculation of the settled trickling filter effluent.

Operational problems have been experienced with filter flies which have been effectively controlled by flooding each filter (except roughing T.F.) once per week during the fly season (March to November). It appears that the weekly flooding (especially for standard rate T.F.) is the explanation for the absence of ponding or odor problems with the filter operation.

The Dallas Wastewater Treatment Plant (standard rate T.F.) is operating at design capacity, while the White Rock Wastewater Treatment Plant (high rate T.F. preceded by roughing T.F.) is operating considerably beyond its design capacity.


ANAEROBIC SUPERNATANT
SETTLED SEWAGE
PRIMARY CLARIFIERS
RAW SEWAGE
WASTE SLUDGE
CLARIFIER UNDERFLOW
TRICKLING FILTERS
EFFLUENT
SECONDARY CLARIFIERS
FILTER EFFLUENT
RECIRCULATION

PLANT FLOW DIAGRAM

```
                        CITY OF DALLAS, TEXAS - CENTRAL PLANT
                            STD.RATE TRICKLING FILTER
                         CURRENT PLANT IN OPERATION - 1940

           PLANT FLOW                                        PLANT DESIGN

                       DESIGN       TYPICAL        TRICKLING FILTERS       CLARIFIERS

AVG DRY WEATHER,MGD     32.0         31.0         NUMBER          16      NUMBER            3
MAX DAY,MGD             60.0         60.0         DIAMETER,FT    176.     LENGTH,FT       100.
PEAK HOUR,MGD           60.0         60.0         DEPTH,FT        7.5     WIDTH,FT         75.
% INDUSTRIAL                         20.          AREA-EACH,SF  24328.    DEPTH,FT         11.2
                                                  VOL-EACH,CF  182464.    AREA-EACH,SF   7500.
                                                                          WEIR LENGTH,FT  150.
                                                                          WEIR TYPE      V-NOTCH
                                                                          SLUDGE REMOVAL  FLIGHT


           PLANT LOADING                                      PLANT PERFORMANCE

                                                                           DESIGN   TYPICAL
TRICKLING FILTERS               DESIGN      TYPICAL

  INF BOD5,MG/L                  210.        210.       EFF BOD5,MG/L       25.0     25.0
  INF SS,MG/L                     94.         94.       % BOD5 REMOVAL      88.      88.
  ORG LOAD,LBBOD5/1000CF/DAY      19.         19.       EFF SS,MG/L         42.0     42.0
  HYD LOAD, MGD/ACRE               6.          6.       % SS REMOVAL        55.      55.
  RECIRCULATION,%                 60.         60.

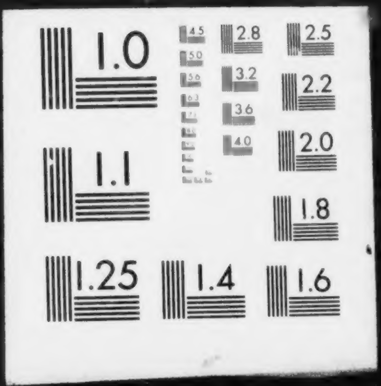

SECONDARY CLARIFIERS              DESIGN                 TYPICAL
                            MAX DAY      AVG        MAX DAY      AVG

  SURFACE LOADING,GAL/SF/DAY  2667.     1428.        2667.     1378.
  WEIR LOADING,GAL/FT/DAY   133333.    71111.      133333.    68889.
  DETENTION TIME,HOURS          0.8       1.4          0.8       1.5
```

4 OF 4

PB

279474


1.0
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1.6

CITY OF FORT LAUDERDALE, FLORIDA - PLANT A

General Description

The wastewater treatment plant is a conventional activated sludge plant. The plant is also designed to operate in the step feed aeration mode. Aeration is provided by multiple low speed surface aerators. The depth of aerator submergence is varied with a weir that increases or decreases the mixed liquor depth. Varying the mixed liquor depth provides control of the aeration rate.

Waste solids are processed in a wet air oxidation system. The centrate from the oxidized sludge is returned to the headworks. When the wet air oxidation system is operating, the primary effluent often has a higher BOD concentration than the raw sewage.

The plant treats wastewaters from light industrial and domestic areas. Average dry weather flow is 7 mgd of which 60% is due to industry. Peak flows occur in the summer during tourist season. The plant effluent is discharged to an estuary.

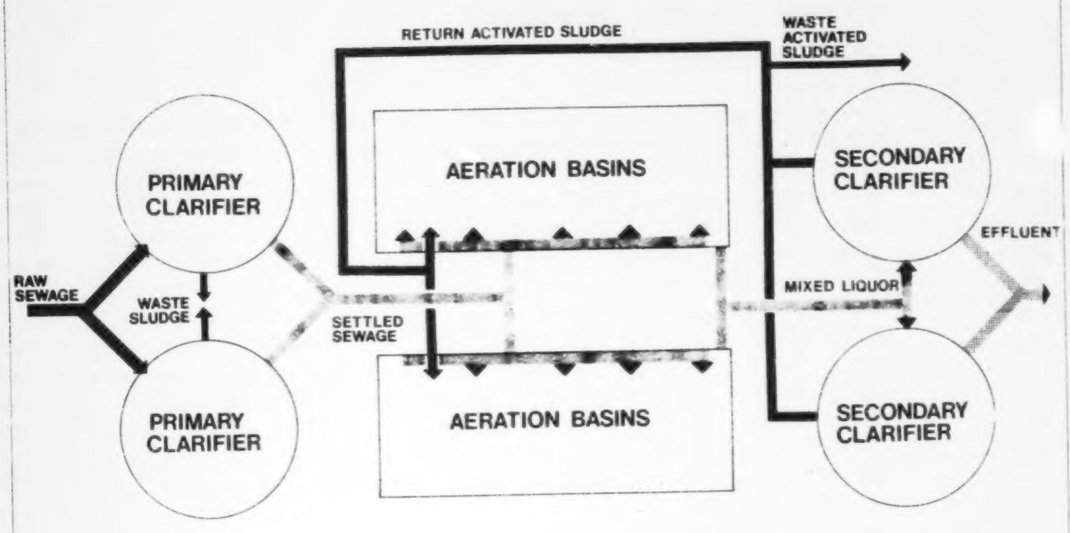
Performance

Effluent concentrations of BOD and SS are typically 25 and 15 mg/l, respectively. The settled sewage has a BOD of 125 mg/l when the wet air oxidation system is in use.

Process Control

The F/M is held around 0.15 to 0.2 lbs BOD_5 removed/lb MLVSS/day. Actual wasting is controlled to maintain constant MLSS. The organic loading is nearly constant, and a constant MLSS fixes the F/M. D.O. is maintained around 2 mg/l by adjusting the mixed liquor depth.

Settleability of the mixed liquor was improved by continual dosing of the return activated sludge with 4 mg/l of Cl_2. Settleability also improved by over aerating the biological solids in the aeration basin at night.


RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE
PRIMARY CLARIFIER
AERATION BASINS
SECONDARY CLARIFIER
EFFLUENT
RAW SEWAGE
WASTE SLUDGE
MIXED LIQUOR
SETTLED SEWAGE
PRIMARY CLARIFIER
AERATION BASINS
SECONDARY CLARIFIER

PLANT FLOW DIAGRAM

CITY OF FT. LAUDERDALE, FLORIDA - PLANT A
CONVENTIONAL ACTIVATED SLUDGE
CURRENT PLANT IN OPERATION - 1971

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	8.2	7.0
MAX DAY,MGD	8.2	8.0
PEAK HOUR,MGD	12.0	12.0
% INDUSTRIAL		60.

PLANT DESIGN

AERATION BASINS

NUMBER	2
LENGTH,FT	165.
WIDTH,FT	55.
DEPTH,FT	13.0
AREA-EACH,SF	9075.

CLARIFIERS

NUMBER	2
DIAMETER,FT	85.
DEPTH,FT	12.0
AREA-EACH,SF	5674.
WEIR LENGTH,FT	270.
WEIR TYPE	V-NOTCH
SLUDGE REMOVAL	VACUUM

AERATION SYSTEM

SYSTEM	MECHANICAL
TYPE	SURFACE
NUMBER	6
HP-EACH	60.
MAX LB O2/DAY	720.
AVG LB O2/DAY	641.

PLANT LOADING

AERATION BASINS	DESIGN	TYPICAL
INF BOD5,MG/L	100.	100.
INF SS,MG/L	100.	100.
F/M,LB BOD5 REM/LB MLVSS/DAY	0.35	0.15
MCRT,DAYS	7.4	7.7
SLUDGE AGE,DAYS	5.3	6.3
MLSS,MG/L	2500.	2500.
MAX MLSS,MG/L		2800.
MIN MLSS,MG/L		2200.
% VOLATILE		75.
D.O. LEVELS,MG/L	2.0	2.0
RETURN, %	64.	46.
MAX RETURN, %	118.	
DET. TIME,@ AVG FLOW,HOURS	5.1	6.1
DET. TIME,@ A.F.+RETURN,HOURS	3.3	4.2
DET. TIME,@ M.F.+RETURN,HOURS	3.3	3.8

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	10.0	30.0
% BOD5 REMOVAL	90.	70.
EFF SS,MG/L	10.0	20.0
% SS REMOVAL	90.	80.
SVI,ML/GRAM		75.
SDI,GRAM/100ML		1.33

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	727.	727.	705.	617.
WEIR LOADING,GAL/FT/DAY	15278.	15278.	14815.	12963.
DETENTION TIME,HOURS	3.0	3.0	3.1	3.5
SOLIDS LOADING,LBS/SF/HOUR	0.98	0.98	0.86	0.78

CITY OF FREMONT, NEBRASKA

General Description

Fremont's treatment facilities consist of two primary clarification, followed by fixed-nozzle trickling filters or roughing filters, followed by intermediate clarification, activated sludge, final clarification, chlorination, and discharge. The Fremont, Nebraska Wastewater Treatment Plant went into operation in March 1975, and, to date, the operators have had very few problems with their aerobic treatment units. The plant design allows a great deal of flexibility in flow schemes. Each unit from the primary clarifiers to the final clarifiers is duplicated; that is, there are two primary clarifiers, two trickling filters, two intermediate clarifiers, etc. The plant piping is such that effluent from each unit joins at a splitter box where it is combined, then resplit to flow to each of the two following units. The splitter boxes are designed so that flow can be split evenly to each unit or any one unit can be taken off line, such as one aeration tank or final clarifier or intermediate clarifier, and all of the flow can be routed through the duplicate unit. There have been some mechanical equipment failures whereby it was necessary to use this capability to reroute the flow around one of the aeration basins.

Performance and Process Control

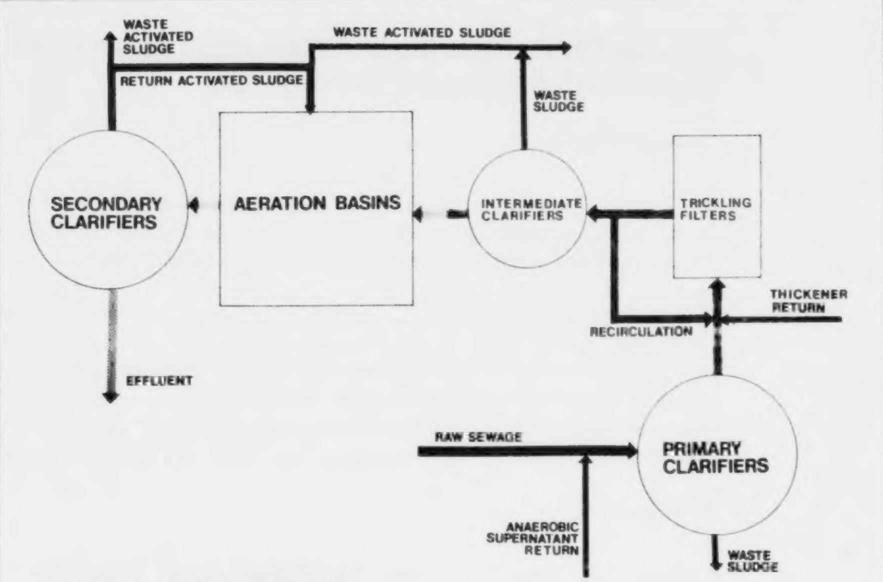
Normally, 2.0 mg/l minimum dissolved oxygen (D.O.) is controlled by adjusting the air flow rate to the diffusers beneath the turbine generators. Control of air flow is accomplished manually.

To date, Fremont, Nebraska has not had foaming problems in the aeration basins other than the normal foaming encountered during start-up. They have had no toxic loads and no bulking sludge to date. They have had some problems with rising sludge. Their solution to that problem is to increase their return rate and to lower the mixed liquor concentration by wasting sludge. Effectively, this cuts the sludge age down and tends to inhibit nitrification.

The plant is controlled on the basis of suspended solids balance. A mixed liquor suspended solids between 3,000 and 4,000 mg/l is the goal that they strive for. The sludge is wasted based upon the sludge blanket depth in the clarifiers. Sludge is wasted to lower the depth of the sludge blanket. The sludge blanket's depth is measured regularly by means of a flashlight on a long pole.

The return sludge system can be operated in an automatic or manual mode. In the automatic mode, the return sludge rate may be set proportionally to influent flow. They have had problems with flow proportional RAS in the low plant influent flow ranges. The flow rate is set by throttling RAS with a motor-operated butterfly valve. This valve and a magnetic flow meter are in the gravity line between the clarifier and the RAS sump. The RAS flows by gravity to a sump where it is picked up by a pump and returned to the aeration basin. The pumping rate is determined by sump level. The present method of operating is to set the return sludge rate manually at some fixed rate.

Sludge is wasted with a system similar to the RAS system. A butterfly valve on a gravity line is manually set to waste at a fixed rate through a mag meter to a WAS sump. WAS is pumped from the sump to a gravity thickener where it is mixed with intermediate sludge and primary sludge. An alternative wasting point is the primary clarifier. The solids handling facilities have the potential of affecting the activated sludge process in that they may limit the rate of sludge wasting and thus affect the suspended solids level in the aeration basins under certain conditions.


WASTE ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE
RETURN ACTIVATED SLUDGE
WASTE SLUDGE
SECONDARY CLARIFIERS
AERATION BASINS
INTERMEDIATE CLARIFIERS
TRICKLING FILTERS
THICKENER RETURN
RECIRCULATION
EFFLUENT
RAW SEWAGE
PRIMARY CLARIFIERS
ANAEROBIC SUPERNATANT RETURN
WASTE SLUDGE

PLANT FLOW DIAGRAM

CITY OF FREMONT, NEBRASKA
COMPLETE MIX ACTIVATED SLUDGE WITH ROUGHING FILTERS
CURRENT PLANT IN OPERATION - 1975

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	7.5	4.0
MAX DAY,MGD	10.5	6.0
PEAK HOUR,MGD	16.0	8.0
% INDUSTRIAL		40.

PLANT DESIGN

AERATION BASINS

NUMBER	2
LENGTH,FT	100.
WIDTH,FT	100.
DEPTH,FT	8.0
AREA-EACH,SF	10000.

CLARIFIERS

NUMBER	2
DIAMETER,FT	90.
DEPTH,FT	10.0
AREA-EACH,SF	6362.
WEIR LENGTH,FT	527.
WEIR TYPE	V-NOTCH
SLUDGE REMOVAL	VACUUM

AERATION SYSTEM

SYSTEM	MECHANICAL
TYPE	TURBINE
NUMBER	8
HP-EACH	50.
MAX LB 02/DAY	480.
AVG LB 02/DAY	480.

TRICKLING FILTERS

NUMBER	2
LENGTH,FT	80.
WIDTH,FT	40.
DEPTH,FT	10.0
AREA-EACH,SF	3217.
VOL-EACH,CF	32170.

PLANT LOADING

TRICKLING FILTERS	DESIGN	TYPICAL
INF BOD5,MG/L	600.	600.
INF SS,MG/L	400.	400.
ORG LOAD,LBBOD5/1000CF/DAY	580.	311.
HYD LOAD, MGD/ACRE	127.	68.
RECIRCULATION,%	150.	150.

AERATION BASINS	DESIGN	TYPICAL
INF BOD5,MG/L	200.	180.
INF SS,MG/L	100.	90.
F/M,LB BOD5 REM/LB MLVSS/DAY	0.40	0.20
MCRT,DAYS	0.	11.7
SLUDGE AGE,DAYS	5.6	11.6
MLSS,MG/L	3400.	3500.
MAX MLSS,MG/L		7000.
MIN MLSS,MG/L		3000.
% VOLATILE		80.
D.O. LEVELS,MG/L	2.0	1.0
RETURN, %	75.	150.
MAX RETURN, %	250.	
DET. TIME,@ AVG FLOW,HOURS	3.8	7.2
DET. TIME,@ A.F.+RETURN,HOURS	2.7	2.9
DET. TIME,@ M.F.+RETURN,HOURS	2.1	2.4

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	825.	589.	472.	314.
WEIR LOADING,GAL/FT/DAY	9962.	7116.	5693.	3795.
DETENTION TIME,HOURS	2.2	3.0	3.8	5.7
SOLIDS LOADING,LBS/SF/HOUR	1.25	0.98	1.15	0.96

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	40.0	11.0
% BOD5 REMOVAL	93.	98.
EFF SS,MG/L	20.0	15.0
% SS REMOVAL	95.	96.
SVI,ML/GRAM		100.
SDI,GRAM/100ML		1.00

INDIANAPOLIS, INDIANA - WASTEWATER TREATMENT PLANT NO. 2 SOUTHPORT ROAD AND WHITE RIVER

General Description

The activated sludge system can be operated as conventional, step aeration or bio-absorption process. Various processes are run throughout the year, and are dependent upon waste strength and influent flow characteristics.

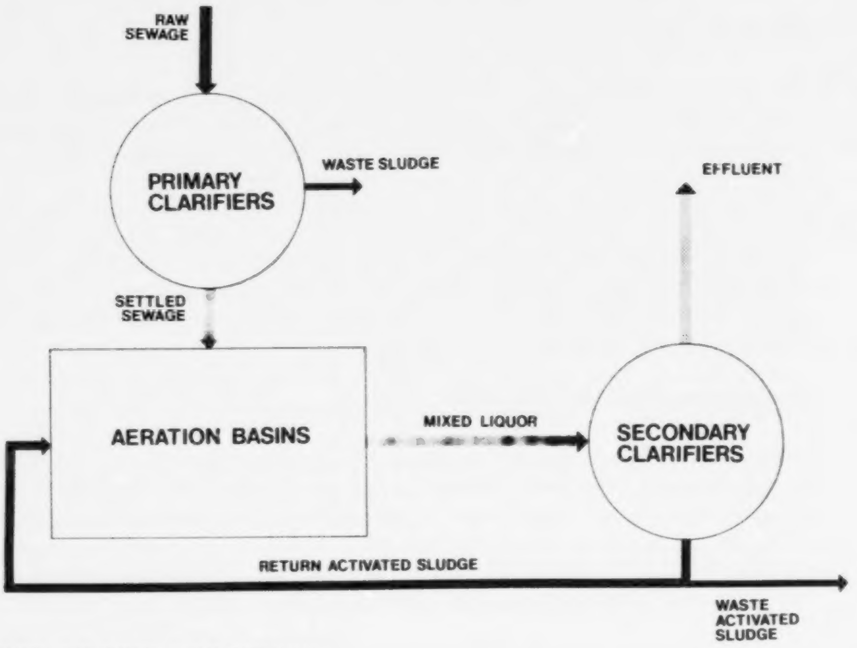
Hydraulic monitoring, control, and distribution is the primary operating features. All force main type process flows are controlled by means of magnetic flow meters with remote readout and remotely-actuated valves. Likewise, gravity (open channel) flow is monitored and controlled by Parshall flumes with flow indicators and remotely-actuated slide gates. One exception to the above is that gravity flows to the various points in the aeration basins are distributed by manually-operated slide gates.

Performance

Process balancing is facilitated by the ability to transfer RAS or WAS flows between unit processes within the plant. Another unique design feature is that primary sludge can be introduced into the secondary clarifiers. As a safety feature only, influent wastewater flows can be bypassed to other in-plant processes.

Process Control

Fundamentally the plant is operated simply by the sludge blanket in the secondary clarifier. The RAS vs. WAS proportion is determined by the current BOD loading on the aeration basins. The sludge draw-off is adjusted once to twice a day based on diurnal flow, and/or upon the observation of shock loading.


RAW SEWAGE
PRIMARY CLARIFIERS
WASTE SLUDGE
EFFLUENT
SETTLED SEWAGE
AERATION BASINS
MIXED LIQUOR
SECONDARY CLARIFIERS
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE

PLANT FLOW DIAGRAM

CITY OF INDIANAPOLIS, INDIANA - SOUTHPORT PLANT
CONVENTIONAL ACTIVATED SLUDGE
CURRENT PLANT IN OPERATION - 1968

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	28.0	35.0
MAX DAY,MGD	42.0	45.0
PEAK HOUR,MGD	42.0	60.0
% INDUSTRIAL		86.

PLANT DESIGN

AERATION BASINS	
NUMBER	4
LENGTH,FT	752.
WIDTH,FT	30.
DEPTH,FT	15.0
AREA-EACH,SF	22560.

CLARIFIERS	
NUMBER	4
DIAMETER,FT	100.
DEPTH,FT	8.0
AREA-EACH,SF	7854.
WEIR LENGTH,FT	314.
WEIR TYPE	V-NOTCH
SLUDGE REMOVAL	PLOW

AERATION SYSTEM

SYSTEM	DIFFUSED
TYPE	SPARGER
MAX SCFM	50000.
AVG SCFM	41000.

PLANT LOADING

AERATION BASINS	DESIGN	TYPICAL
INF BOD5,MG/L	240.	110.
INF SS,MG/L	112.	75.
F/M,LB BOD5 REM/LB MLVSS/DAY	0.50	0.27
MCRT,DAYS	7.5	6.5
SLUDGE AGE,DAYS	5.8	6.7
MLSS,MG/L	1800.	1725.
MAX MLSS,MG/L		2000.
MIN MLSS,MG/L		1300.
% VOLATILE		70.
D.O. LEVELS,MG/L	2.0	3.3
AIR APPLIED,SCF/GAL		1.7
AIR APPLIED,SCF/LB BOD5 REM		2175.
RETURN, %	38.	47.
MAX RETURN, %	114.	
DET. TIME,@ AVG FLOW,HOURS	8.7	6.9
DET. TIME,@ A.F.+RETURN,HOURS	5.9	4.7
DET. TIME,@ M.F.+RETURN,HOURS	4.4	4.0

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	24.0	17.0
% BOD5 REMOVAL	90.	85.
EFF SS,MG/L	12.5	12.0
% SS REMOVAL	89.	84.
SVI,ML/GRAM		200.
SDI,GRAM/100ML		0.50

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	1337.	891.	1337.	1114.
WEIR LOADING,GAL/FT/DAY	33439.	22293.	35828.	27866.
DETENTION TIME,HOURS	1.1	1.6	1.0	1.3
SOLIDS LOADING,LBS/SF/HOUR	1.10	0.82	1.17	0.98

CITY OF KENOSHA, WISCONSIN

General Description

The water pollution control plant facilities at Kenosha, Wisconsin consist essentially of a conventional activated sludge process, with solids treatment incorporating flotation thickening, anaerobic digestion, and dewatering by pressure filters.

This plant is designed to handle an average dry weather flow of 23 mgd. Currently, the industrial contribution is averaging 67 percent of the average dry weather flow. Since the combined sewer system contributes high hydraulic loads on the facilities during rainfall, the utility also placed in operation the world's first biosorption treatment system. This is a 20 mgd project to demonstrate the biological treatment of combined sewer overflows during periods of rainfall.

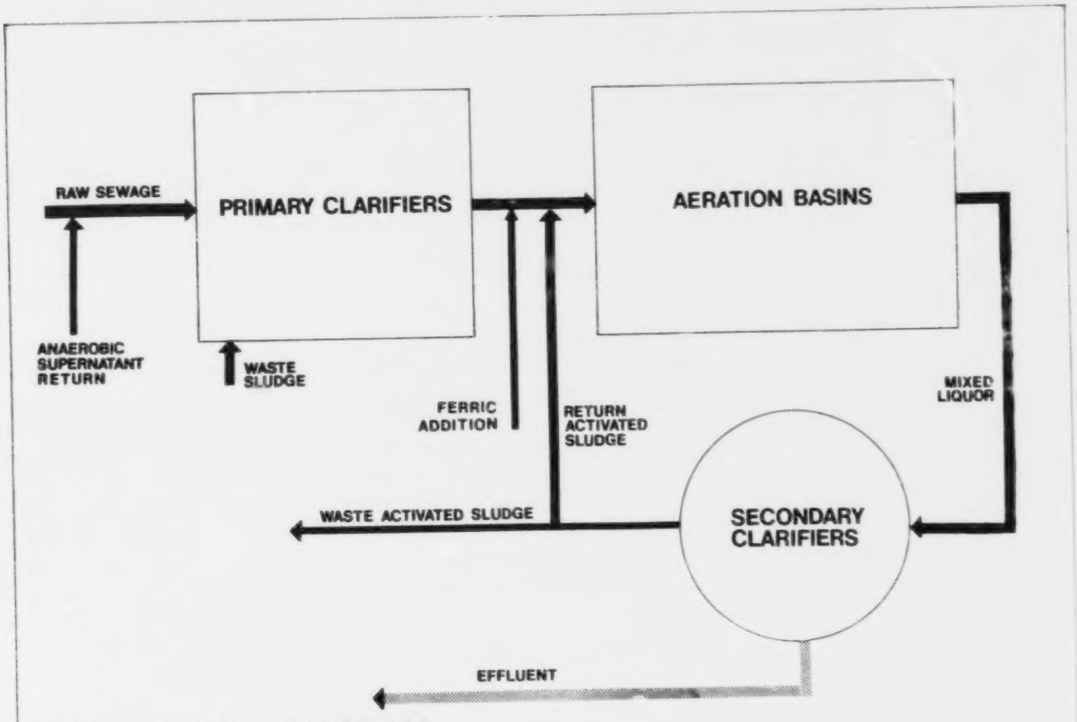
Performance and Process Control

The activated sludge system consists of four single-pass basins, with return activated sludge applied at the influent channel. Variations of RAS application other than at the influent channel are insignificant in importance. The alternate application points are at the beginning and end of the first aeration basin. Dissolved oxygen in the various basins are maintained at a level of 1 to 2 mg/l. Air feed rates are generally not varied, due to difficulty in manually adjusting these rates.

The four final clarifiers are the peripheral feed, center suction sludge discharge variety. A common header with connections to each clarifier is used for pumping. Each pump is variable speed; however, only three pumps are provided for the four tanks, thus making controlled takeoff difficult. Although the pumps are variable speed, the RAS flow rates are not varied. The rate of flow is controlled through the use of a magnetic flow meter in the line returning to the aeration basin.

The amount of waste activated sludge (WAS) is controlled by the MLSS concentration level in the aeration basin. WAS is taken from the RAS line and fed to an open aerated pit, where eventually the sludge will be fed to the flotation thickeners. Rate is varied to maintain an MLSS level between 2,500 to 3,000 mg/l.

The most serious control problem is that associated with the hydraulic distribution of flow to the four secondary clarifiers. The problem arises from the fact that the last expansion added a secondary clarifier which itself is approximately 50 percent larger than the initial three secondary clarifiers. The distribution channels were designed solely to feed the initial three clarifiers; therefore, flow to the new and larger clarifier is much below design capacity. Consequently, during large increases in flow, the remaining three clarifiers tend to be hydraulically overloaded.


RAW SEWAGE
PRIMARY CLARIFIERS
AERATION BASINS
ANAEROBIC SUPERNATANT RETURN
WASTE SLUDGE
FERRIC ADDITION
RETURN ACTIVATED SLUDGE
MIXED LIQUOR
WASTE ACTIVATED SLUDGE
SECONDARY CLARIFIERS
EFFLUENT

PLANT FLOW DIAGRAM

CITY OF KENOSHA, WISCONSIN
CONVENTIONAL ACTIVATED SLUDGE
CURRENT PLANT IN OPERATION - 1972

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	23.0	20.0
MAX DAY,MGD	26.0	23.0
PEAK HOUR,MGD	30.0	30.0
% INDUSTRIAL		67.

PLANT DESIGN

AERATION BASINS

NUMBER	4
VOLUME, CU FT	122,000.

CLARIFIERS

NUMBER	4
DIAMETER,FT	100.
DEPTH,FT	11.0
AREA-EACH,SF	7854.
WEIR LENGTH,FT	255.
WEIR TYPE	V-NOTCH
SLUDGE REMOVAL	VACUUM

AERATION SYSTEM

SYSTEM	DIFFUSED
TYPE	SPARGER
MAX SCFM	13350.
AVG SCFM	8700.

PLANT LOADING

AERATION BASINS	DESIGN	TYPICAL
INF BOD5,MG/L	80.	73.
INF SS,MG/L	75.	75.
F/M,LB BOD5 REM/LB MLVSS/DAY	0.13	0.16
MCRT,DAYS	0.	8.0
SLUDGE AGE,DAYS	7.5	8.8
MLSS,MG/L	2500.	3600.
MAX MLSS,MG/L		4000.
MIN MLSS,MG/L		2000.
% VOLATILE		63.
D.O. LEVELS,MG/L	2.0	1.5
AIR APPLIED,SCF/GAL		0.6
AIR APPLIED,SCF/LB BOD5 REM		1121.
RETURN, %	54.	46.
MAX RETURN, %	47.	
DET. TIME,@ AVG FLOW,HOURS	3.8	4.4
DET. TIME,@ A.F.+RETURN,HOURS	2.6	3.0
DET. TIME,@ M.F.+RETURN,HOURS	2.4	2.7

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	10.0	6.0
% BOD5 REMOVAL	87.	92.
EFF SS,MG/L	10.0	31.0
% SS REMOVAL	87.	59.
SVI,ML/GRAM		116.
SDI,GRAM/100ML		0.86

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	828.	732.	829.	637.
WEIR LOADING,GAL/FT/DAY	25391.	22461.	22461.	19531.
DETENTION TIME,HOURS	2.4	2.7	2.7	3.1
SOLIDS LOADING,LBS/SF/HOUR	1.01	0.93	1.29	1.17

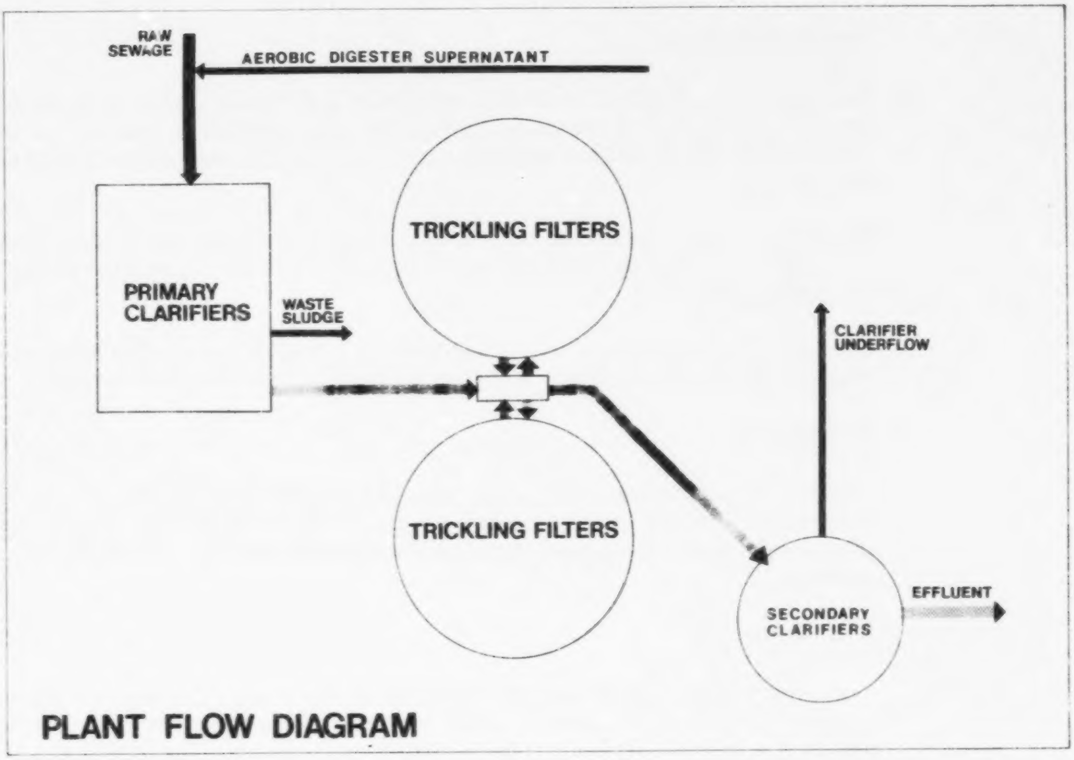
LAS VEGAS, NEVADA - CLARK COUNTY SANITATION DISTRICT NO. 1 TREATMENT PLANT

General Description

In 1956 Clark County Sanitation District No. 1 put their 12 mgd trickling filter in service. In 1974 an addition to the original plant was put into operation, increasing the capacity to a total of 32 mgd. At this time, solids incineration was added.

Performance and Process Control

The treatment plant has had few operating problems, being a high-rate single-stage filter plant. The main problems have been mechanical maintenance problems rather than serious operational problems. There is enough capacity in process units to provide standby/backup capability when necessary. Here again, operation of the plant is not significantly affected by the weather. One problem experienced at this plant has been large amounts of freshwater snails accumulating in the chlorine contact tank. Anticipating a continuation of this problem, a traveling bridge collector was installed in the new chlorine contact tank, but the problem has been diminishing steadily since the new portion of the plant has been put into operation. There have been operations problems with the incinerator which have no effect on the operation of the trickling filter plant.


RAW SEWAGE
AEROBIC DIGESTER SUPERNATANT
PRIMARY CLARIFIERS
WASTE SLUDGE
TRICKLING FILTERS
TRICKLING FILTERS
CLARIFIER UNDERFLOW
SECONDARY CLARIFIERS
EFFLUENT

PLANT FLOW DIAGRAM

LAS VEGAS, NEVADA - CLARK COUNTY PLANT
STANDARD RATE TRICKLING FILTER
CURRENT PLANT IN OPERATION - 1974

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	32.0	27.0
MAX DAY,MGD	53.0	34.0
PEAK HOUR,MGD	53.0	34.0
% INDUSTRIAL		0.

PLANT DESIGN

TRICKLING FILTERS		CLARIFIERS	
NUMBER	5	NUMBER	5
DIAMETER,FT	190.	DIAMETER,FT	100.
DEPTH,FT	5.0	DEPTH,FT	9.2
AREA-EACH,SF	28353.	AREA-EACH,SF	7854.
VOL-EACH,CF	141764.	WEIR LENGTH,FT	620.
		WEIR TYPE	V-NOTCH
		SLUDGE REMOVAL	PLOW

PLANT LOADING

TRICKLING FILTERS	DESIGN	TYPICAL
INF BOD5,MG/L	147.	74.
INF SS,MG/L	87.	220.
ORG LOAD,LBBOD5/1000CF/DAY	55.	24.
HYD LOAD, MGD/ACRE	29.	37.
RECIRCULATION,%	100.	340.

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	20.0	7.4
% BOD5 REMOVAL	[illegible]	90.
EFF SS,MG/L	20.0	22.0
% SS REMOVAL	77.	90.

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	1350.	815.	866.	688.
WEIR LOADING,GAL/FT/DAY	17097.	10323.	10968.	8710.
DETENTION TIME,HOURS	1.2	2.0	1.9	2.4

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LOWER POTOMAC POLLUTION CONTROL PLANT, LORTON, VA.

General Description

The wastewater treatment plant is a conventional activated sludge plant utilizing the contact stabilization mode of operation. Diffused aeration is provided by positive displacement blowers. Each aeration basin has three passes with the first pass used for reaeration.

Waste solids are transferred to gravity thickeners followed by vacuum filters and incineration. Thickener effluent, filtrate, and spent cooling water are returned to the plant headworks.

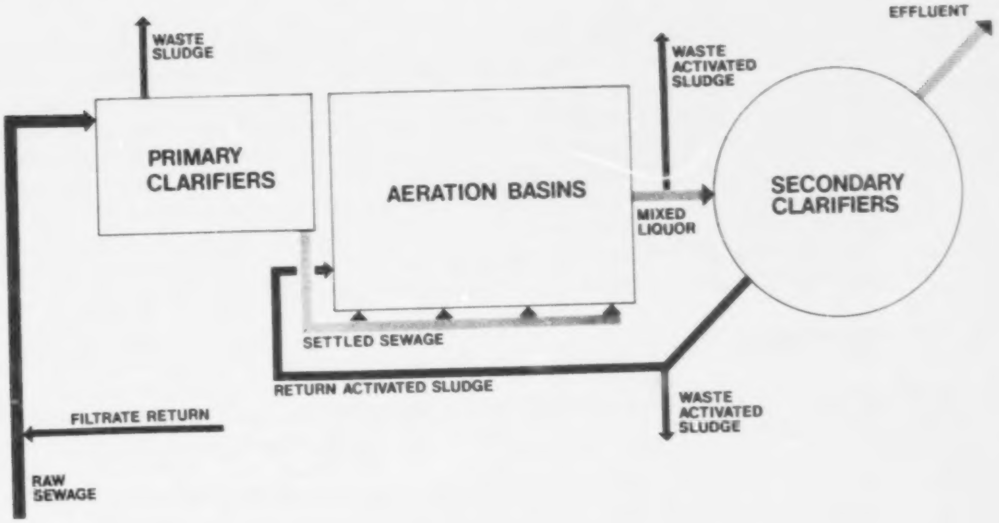
The plant treats wastes primarily from domestic sources. Average dry weather flow is 15.0 mgd. Design average flow is 18.0 mgd. Effluent is discharged to a creek.

Performance

Effluent concentrations of BOD and suspended solids are typically 14 and 13 mg/l, respectively. Settled wastewater has a typical BOD concentration of 220 mg/l. The side stream flows, being transferred to the plant headworks, causes higher organic loadings.

Process Control

The primary control parameter for this plant is the Sludge Compaction Ratio (SCR) method. The SCR is computed by obtaining mean values of 24 30-minute settling tests and 24 spin(centrifuge) tests of hourly MLSS grab samples. The SCR is equal to the settling mean value divided by the spin mean value times 83.4. The number for operational control is computed by multiplying the SCR by 100 and adding the settling mean value. For this plant, the control number of 500 appears provide optimum operation. The control number is maintained by solids wasting and is also used as an indicator for the addition of polymers. At this time no correlation of the control number has been made to other process controls such as F/M, MCRT, etc.


WASTE SLUDGE
PRIMARY CLARIFIERS
AERATION BASINS
WASTE ACTIVATED SLUDGE
EFFLUENT
SECONDARY CLARIFIERS
MIXED LIQUOR
SETTLED SEWAGE
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE
FILTRATE RETURN
RAW SEWAGE

PLANT FLOW DIAGRAM

```
                 CITY OF LORTON, VIRGINIA - LOWER POTOMAC PLANT
                          STEP FEED ACTIVATED SLUDGE
                       CURRENT PLANT IN OPERATION - 1973

                                                              PLANT DESIGN
              PLANT FLOW
                                                                             CLARIFIERS
                           DESIGN      TYPICAL        AERATION BASINS

                                                      NUMBER            2    NUMBER               3
   AVG DRY WEATHER,MGD      18.0        15.1          LENGTH,FT         0.   DIAMETER,FT        120.
   MAX DAY,MGD              20.0        20.0          WIDTH,FT          0.   DEPTH,FT            12.0
   PEAK HOUR,MGD            22.0        22.0          DEPTH,FT          0.   AREA-EACH,SF     11310.
   % INDUSTRIAL                         50.           AREA-EACH,SF      0.   WEIR LENGTH,FT     367.
                                                                             WEIR TYPE       V-NOTCH
                                                                             SLUDGE REMOVAL   VACUUM
               PLANT LOADING                          AERATION SYSTEM

                                    DESIGN      TYPICAL   SYSTEM        DIFFUSED
 AERATION BASINS                                          TYPE              SOCK
                                     200.        200.     MAX SCFM      31000.
   INF BOD5,MG/L                     200.        200.     AVG SCFM      13000.
   INF SS,MG/L                        0.30        1.38
   F/M,LB BOD5 REM/LB MLVSS/DAY       5.0         1.5
   MCRT,DAYS                          0.6         0.8
   SLUDGE AGE,DAYS                   625.        625.
   MLSS,MG/L                                     800.
   MAX MLSS,MG/L                                 500.
   MIN MLSS,MG/L                                  85.
   % VOLATILE                         1.5         2.0
   D.O. LEVELS,MG/L                               1.2           PLANT PERFORMANCE
   AIR APPLIED,SCF/GAL                           804.
   AIR APPLIED,SCF/LB BOD5 REM                    46.                        DESIGN     TYPICAL
   RETURN, %                          40.
   MAX RETURN, %                     199.                 EFF BOD5,MG/L       15.0       15.0
   DET. TIME,@ AVG FLOW,HOURS         5.1         6.0     % BOD5 REMOVAL      93.        93.
   DET. TIME,@ A.F.+RETURN,HOURS      3.6         4.1     EFF SS,MG/L         15.0       15.0
   DET. TIME,@ M.F +RETURN,HOURS      3.4         3.4     % SS REMOVAL        93.        93.
                                                          SVI,ML/GRAM                   180.
                                                          SDI,GRAM/100ML                  0.56

                                        DESIGN                    TYPICAL
 SECONDARY CLARIFIERS              MAX DAY      AVG         MAX DAY       AVG

   SURFACE LOADING,GAL/SF/DAY        589.       531.          589.       445.
   WEIR LOADING,GAL/FT/DAY         18165.     16349.        18165.     13715.
   DETENTION TIME,HOURS               3.7        4.1           3.7        4.8
   SOLIDS LOADING,LBS/SF/HOUR         0.17       0.16          0.17       0.14
```

CITY OF MADERA, CALIFORNIA

General Description

The wastewater treatment plant incorporates the activated biofiltration (ABF) mode of operation. An alternate mode, single-stage high-rate filtration, is also available. The normal mode of operation is with the activated biofiltration process. The ABF process consist of loading two parallel filters at rates of approximately 560 gpm/ft^2 followed by sedimentation. Solids from the settling tanks are returned at a 2:1 ratio, and mixed with primary effluent before being applied to the filters. Waste solids are transferred to the plant headworks and settled in the primary clarifiers. The plant treats wastewater primarily from domestic sources and receives industrial wastes during the canning season. Average dry weather flow is 2.7 mgd with maximum day peaks of 3.5 mgd. Effluent is discharged to evaporation-percolation ponds.

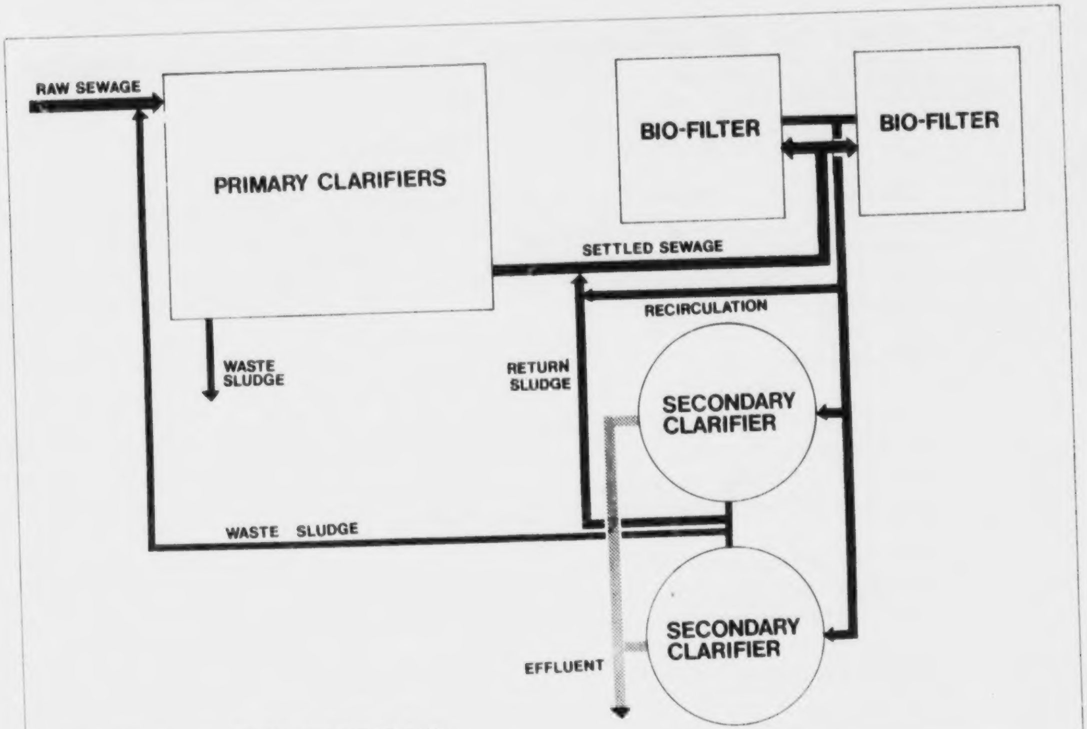
Performance

Effluent concentrations of BOD and suspended solids are typically 30 and 11 mg/l, respectively.

Solids concentrations from the filter effluent are typically 2,600 mg/l. Control of these solids are maintained by the amount of solids wasted from the system.

Process Control

The only process control currently used is maintaining the filter effluent solids at optimum concentrations for various wastewater characteristics during specific times of the year. This control is maintained by wasting solids from the system.


RAW SEWAGE
PRIMARY CLARIFIERS
BIO-FILTER
BIO-FILTER
SETTLED SEWAGE
RECIRCULATION
WASTE SLUDGE
RETURN SLUDGE
SECONDARY CLARIFIER
WASTE SLUDGE
SECONDARY CLARIFIER
EFFLUENT

PLANT FLOW DIAGRAM

CITY OF MADERA, CALIFORNIA
ACTIVATED BIO-FILTER
CURRENT PLANT IN OPERATION - 1972

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	7.0	2.7
MAX DAY,MGD	11.0	3.5
PEAK HOUR,MGD	11.0	5.0
% INDUSTRIAL		50.

PLANT DESIGN

TRICKLING FILTERS		CLARIFIERS	
NUMBER	2	NUMBER	2
LENGTH,FT	60.	DIAMETER,FT	75.
WIDTH,FT	60.	DEPTH,FT	12.0
DEPTH,FT	12.0	AREA-EACH,SF	4418.
AREA-EACH,SF	3739.	WEIR LENGTH,FT	236.
VOL-EACH,CF	44871.	WEIR TYPE	V-NOTCH
		SLUDGE REMOVAL	VACUUM

PLANT LOADING

TRICKLING FILTERS	DESIGN	TYPICAL
INF BOD5,MG/L	110.	97.
INF SS,MG/L	110.	90.
ORG LOAD,LBBOD5/1000CF/DAY	75.	24.
HYD LOAD, MGD/ACRE	160.	47.
RECIRCULATION,%	200.	200.

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	30.0	20.0
% BOD5 REMOVAL	73.	79.
EFF SS,MG/L	30.0	22.0
% SS REMOVAL	73.	76.

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	1245.	792.	396.	306.
WEIR LOADING,GAL/FT/DAY	23355.	14862.	7431.	5732.
DETENTION TIME,HOURS	1.7	2.7	5.4	7.0

CITIES OF NEENAH-MENASHA, WISCONSIN - SEWAGE TREATMENT PLANT

General Description

The treatment facilities are designed to operate primarily as a conventional activated sludge (CAS) or contact stabilization system. The contact stabilization mode has been tried periodically, and the results have been unsatisfactory. Tapered aeration was tried but resulted in clogged diffusers. Therefore, CAS is the only feasible mode of operation.

Performance

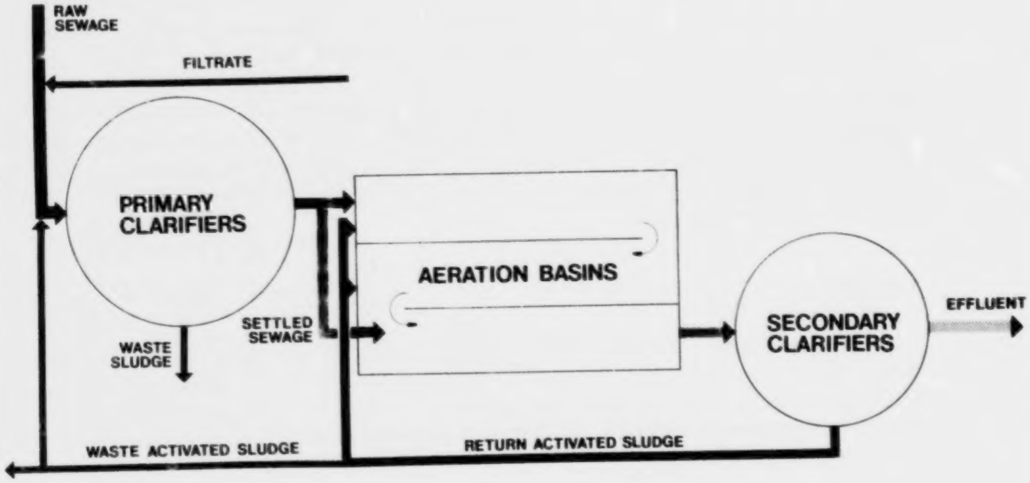
The primary facilities are designed to discharge only 13 mgd to the activated sludge system. Although the aeration facilities are designed to handle 18 mgd, the RAS held constant at 9.0 mgd make the ADWF to the system near 22 mgd. Flow in excess of 13 mgd out of the primaries is hydraulically diverted to the interceptor sewer.

The RAS enters a wet well and is controlled by a telescopic valve arrangement. RAS and WAS are pumped from the wet well. The WAS is flotation thickened and pumped to a holding tank. RAS is returned to the head of each of the two aeration basins.

Process Control

Contrary to practice in most plants, the desire in operation is to achieve a relatively high sludge level in the final tanks (correlates with the high SVI average of 210-220 ml/g). Denser sludge blankets are particularly susceptible to lifting, with subsequent poor effluent quality. Standard practice at this facility is to maintain a level of sludge near the effluent weirs. The high SVI level is achieved by maintaining 3-4 mg/l DO in the effluent from the aeration basin.

High DO in the aeration basin is desirable, since at lower levels odor problems persist.


RAW SEWAGE
FILTRATE
PRIMARY CLARIFIERS
AERATION BASINS
SETTLED SEWAGE
WASTE SLUDGE
SECONDARY CLARIFIERS
EFFLUENT
WASTE ACTIVATED SLUDGE
RETURN ACTIVATED SLUDGE

PLANT FLOW DIAGRAM

CITIES OF NEENAH-MENASHA, WISCONSIN
CONVENTIONAL ACTIVATED SLUDGE
CURRENT PLANT IN OPERATION - 1967

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	18.0	13.7
MAX DAY,MGD	30.0	30.0
PEAK HOUR,MGD	46.0	46.0
% INDUSTRIAL		50.

PLANT DESIGN

AERATION BASINS

NUMBER	2
LENGTH,FT	540.
WIDTH,FT	30.
DEPTH,FT	16.0
AREA-EACH,SF	16200.

CLARIFIERS

NUMBER	2
DIAMETER,FT	120.
DEPTH,FT	11.6
AREA-EACH,SF	11310.
WEIR LENGTH,FT	377.
WEIR TYPE	V-NOTCH
SLUDGE REMOVAL	VACUUM

AERATION SYSTEM

SYSTEM	DIFFUSED
TYPE	SPARGER
MAX SCFM	4500.
AVG SCFM	1500.

PLANT LOADING

AERATION BASINS	DESIGN	TYPICAL
INF BOD5,MG/L	144.	123.
INF SS,MG/L	100.	78.
F/M,LB BOD5 REM/LB MLVSS/DAY	0.22	0.12
MCRT,DAYS	0.	8.7
SLUDGE AGE,DAYS	7.5	14.5
MLSS,MG/L	3500.	4000.
MAX MLSS,MG/L		5000.
MIN MLSS,MG/L		3300.
% VOLATILE		75.
D.O. LEVELS,MG/L	2.0	3.0
AIR APPLIED,SCF/GAL		0.2
AIR APPLIED,SCF/LB BOD5 REM		178.
RETURN, %	60.	60.
MAX RETURN, %	110.	
DET. TIME,@ AVG FLOW,HOURS	5.2	6.8
DET. TIME,@ A.F.+RETURN,HOURS	3.4	4.1
DET. TIME,@ M.F.+RETURN,HOURS	2.4	2.4

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	22.0	17.0
% BOD5 REMOVAL	85.	86.
EFF SS,MG/L	32.0	37.0
% SS REMOVAL	68.	53.
SVI,ML/GRAM		235.
SDI,GRAM/100ML		0.43

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	1326.	796.	1326.	606.
WEIR LOADING,GAL/FT/DAY	39788.	23873.	39788.	18170.
DETENTION TIME,HOURS	1.6	2.6	1.6	3.4
SOLIDS LOADING,LBS/SF/HOUR	2.10	1.45	2.40	1.39

CITY OF PALO ALTO, CALIFORNIA

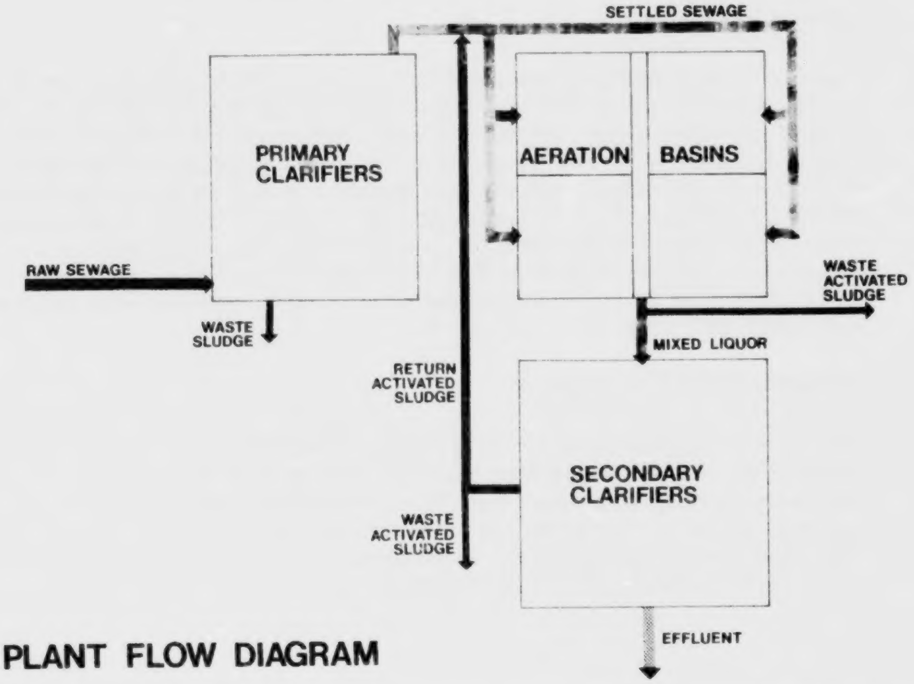
General Description

Due to the inability of the primary plan to meet the more strict discharge requirements, in 1966 it was decided to expand the plant and also treat the wastes from the cities of Mountain View and Los Altos by the activated sludge process.

A regional plant was constructed with primary treatment, activated sludge secondary treatment and solids incineration, the capacity being 35 MGD dry weather flow and 53 MGD wet weather flow. The regional plant was placed in operation in 1972. Plans for the future include expansion to 75 MGD dry weather flow and separate treatment of toxic industrial wastes.

Operation

The plant normally operates in the Complete Mix mode, but has the capability of operating in the Reaeration or Contact Stabilization mode. Reaeration has been tried at the plant, with little success. Sludge (RAS) is returned from the final clarifier with a portion being wasted. Waste sludge and primary sludge are thickened prior to dewatering and incineration.


SETTLED SEWAGE
PRIMARY CLARIFIERS
AERATION BASINS
RAW SEWAGE
WASTE SLUDGE
WASTE ACTIVATED SLUDGE
MIXED LIQUOR
RETURN ACTIVATED SLUDGE
SECONDARY CLARIFIERS
WASTE ACTIVATED SLUDGE
EFFLUENT

PLANT FLOW DIAGRAM

CITY OF PALO ALTO, CALIFORNIA
COMPLETE MIX ACTIVATED SLUDGE
CURRENT PLANT IN OPERATION - 1971

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	35.0	26.5
MAX DAY,MGD	70.0	33.0
PEAK HOUR,MGD	70.0	70.0
% INDUSTRIAL		50.

PLANT DESIGN

AERATION BASINS

NUMBER	4
LENGTH,FT	135.
WIDTH,FT	120.
DEPTH,FT	15.0
AREA-EACH,SF	16200.

CLARIFIERS

NUMBER	4
LENGTH,FT	115.
WIDTH,FT	115.
DEPTH,FT	11.0
AREA-EACH,SF	13225.
WEIR LENGTH,FT	448.
WEIR TYPE	V-NOTCH
SLUDGE REMOVAL	VACUUM

AERATION SYSTEM

SYSTEM	MECHANICAL
TYPE	TURBINE
NUMBER	16
HP-EACH	50.
MAX LB O2/DAY	20000.
AVG LB O2/DAY	20000.

PLANT LOADING

AERATION BASINS	DESIGN	TYPICAL
INF BOD5,MG/L	150.	100.
INF SS,MG/L	84.	60.
F/M,LB BOD5 REM/LB MLVSS/DAY	0.30	0.25
MCRT,DAYS	12.0	3.8
SLUDGE AGE,DAYS	0.	6.9
MLSS,MG/L	2800.	1500.
MAX MLSS,MG/L		1800.
MIN MLSS,MG/L		1000.
% VOLATILE		80.
D.O. LEVELS,MG/L	1.5	2.0
RETURN, %	130.	80.
MAX RETURN, %	130.	
DET. TIME,@ AVG FLOW,HOURS	5.0	6.6
DET. TIME,@ A.F.+RETURN,HOURS	2.5	4.1
DET. TIME,@ M.F.+RETURN,HOURS	1.7	3.6

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	20.0	14.0
% BOD5 REMOVAL	88.	86.
EFF SS,MG/L	20.0	14.0
% SS REMOVAL	71.	77.
SVI,ML/GRAM		200.
SDI,GRAM/100ML		0.50

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	1323.	662.	624.	501.
WEIR LOADING,GAL/FT/DAY	39063.	19531.	18415.	14788.
DETENTION TIME,HOURS	1.5	3.0	3.2	3.9
SOLIDS LOADING,LBS/SF/HOUR	1.78	1.19	0.58	0.42

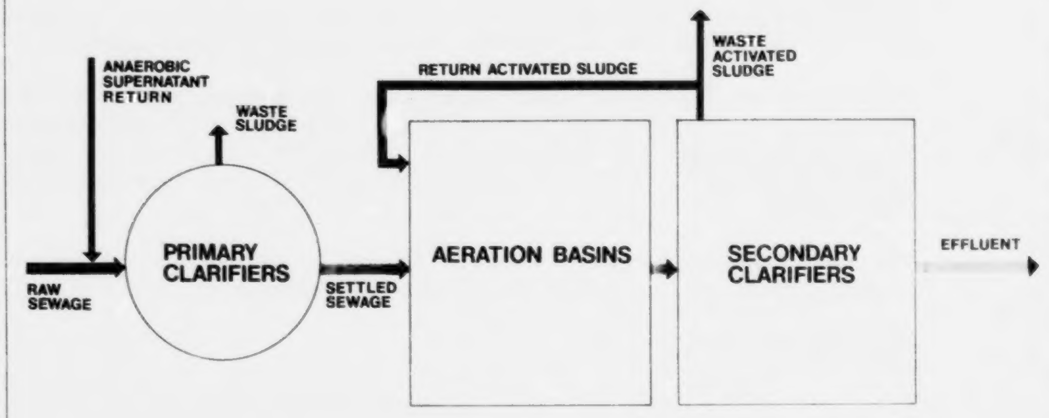
CITY OF PHOENIX, ARIZONA - 91st AVENUE SEWAGE TREATMENT PLANT

General Description

Initially, a 5 mgd trickling filter plant was located at the 91st Avenue site. This plant treated wastewater from Glendale and the west side of Phoenix until late in 1964 when Stage I of the 91st Avenue activated sludge plant was put into operation. The capacity of this first stage was 45 mgd and was part of a five-city (regional) wastewater project. In 1969 a 15 mgd Stage II was put into operation, giving the plant a total capacity of 60 mgd. At present, the 91st Avenue Sewage Treatment Plant is treating wastewater from the cities of Glendale, Phoenix, Tempe, Scottsdale, Mesa, and Sun City. Youngtown and Peoria will be contributing their flows to the plant in the near future. Construction is underway to expand the plant further, and future plans call for an eventual capacity of 240 mgd.

Performance and Process Control

The plant is currently being operated in the conventional mode, but has the capability of being operated in the step-feed mode. The 91st Avenue plant has experienced much the same type of problem with frothing in the aeration basins as the City of Tucson, and they solved it in the same manner by reducing the MLSS level to the 1,200 - 1,600 mg/l range. As in the case of the Tucson plant, this, along with a low sludge age of 2 to 4 days, seems to remedy the frothing problem.



RAW SEWAGE
ANAEROBIC SUPERNATANT RETURN
PRIMARY CLARIFIERS
WASTE SLUDGE
SETTLED SEWAGE
RETURN ACTIVATED SLUDGE
AERATION BASINS
WASTE ACTIVATED SLUDGE
SECONDARY CLARIFIERS
EFFLUENT

PLANT FLOW DIAGRAM

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                              CITY OF PHOENIX, ARIZONA
                           CONVENTIONAL ACTIVATED SLUDGE
                          CURRENT PLANT IN OPERATION - 1969

              PLANT FLOW                                        PLANT DESIGN

                        DESIGN      TYPICAL        AERATION BASINS            CLARIFIERS

      AVG DRY WEATHER,MGD   60.0        60.0        NUMBER             4     NUMBER              24
      MAX DAY,MGD           90.0        90.0        LENGTH,FT        310.    LENGTH,FT           91.
      PEAK HOUR,MGD        105.0       105.0        WIDTH,FT         100.    WIDTH,FT            47.
      % INDUSTRIAL                      50.         DEPTH,FT          15.6   DEPTH,FT             8.0
                                                    AREA-EACH,SF   31000.    AREA-EACH,SF      4254.
                                                                             WEIR LENGTH,FT     300.
                                                                             WEIR TYPE       V-NOTCH
              PLANT LOADING                         AERATION SYSTEM          SLUDGE REMOVAL   FLIGHT

    AERATION BASINS                   DESIGN      TYPICAL     SYSTEM      DIFFUSED
                                                              TYPE         SPARGER
      INF BOD5,MG/L                    235.        118.       MAX SCFM    78600.
      INF SS,MG/L                      145.         65.       AVG SCFM    72000.
      F/M,LB BOD5 REM/LB MLVSS/DAY       0.67        0.39
      MCRT,DAYS                          2.7         2.2
      SLUDGE AGE,DAYS                    3.2         5.2
      MLSS,MG/L                       2000.       1400.
      MAX MLSS,MG/L                               1600.
      MIN MLSS,MG/L                               1200.                  PLANT PERFORMANCE
      % VOLATILE                                    75.
      D.O. LEVELS,MG/L                   2.0         2.0
      AIR APPLIED,SCF/GAL                            1.7                           DESIGN    TYPICAL
      AIR APPLIED,SCF/LB BOD5 REM                 2114.
      RETURN, %                         53.         30.         EFF BOD5,MG/L       20.0      20.0
      MAX RETURN, %                     80.                     % BOD5 REMOVAL      91.       83.
      DET. TIME,@ AVG FLOW,HOURS         5.8         5.8        EFF SS,MG/L         29.0      52.0
      DET. TIME,@ A.F.+RETURN,HOURS      3.8         4.5        % SS REMOVAL        80.       20.
      DET. TIME,@ M.F.+RETURN,HOURS      2.8         3.2        SVI,ML/GRAM                  100.
                                                                SDI,GRAM/100ML                 1.00

    SECONDARY CLARIFIERS                   DESIGN                  TYPICAL
                                    MAX DAY      AVG         MAX DAY       AVG

      SURFACE LOADING,GAL/SF/DAY     882.        588.         882.         588.
      WEIR LOADING,GAL/FT/DAY      12500.       8333.       12500.        8333.
      DETENTION TIME,HOURS             1.6         2.4          1.6          2.4
      SOLIDS LOADING,LBS/SF/HOUR       0.83        0.63         0.51         0.37
```

VILLAGE OF RIDGEWOOD, NEW JERSEY

General Description

The wastewater treatment plant is a conventional activated sludge plant. Design flexibility of the plant allows the contact stabilization mode which is the current mode of operation. Diffused aeration is provided by low pressure centrifugal blowers.

Waste solids are processed by gravity thickening and anaerobic digestion. Additional side stream flows such as digester supernatant and filtrate from the sludge vacuum filters are transferred to the thickener. The thickener effluent undergoes separate aeration before being returned to the treatment process thus limiting additional BOD loads.

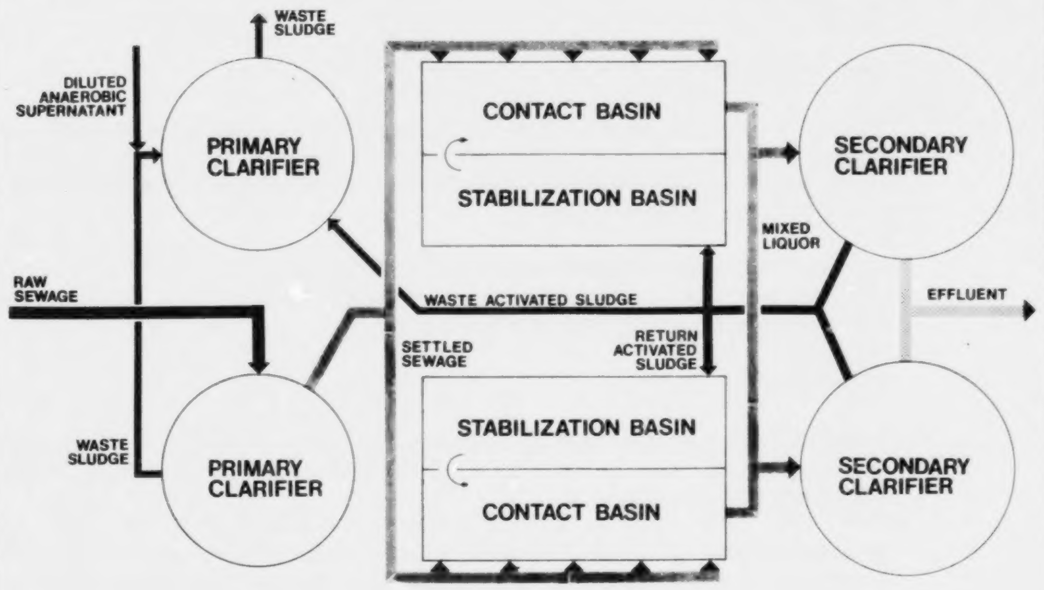
The plant treats primarily domestic wastes. Average dry weather flow is 3.1 mgd with a design average of 5.0 mgd. Plant effluent is discharged to a river.

Performance

Effluent concentrations of BOD and suspended solids are typically 16 and 13 mg/l, respectively. The settled wastewater has a BOD of 130 mg/l.

Process Control

The F/M is held around 0.17 to 0.25 lbs BOD/day/lb MLVSS. The organic loading is nearly constant and by wasting to maintain a constant MLSS fixes the F/M. D.O. is maintained around 2 mg/l by adjusting the blower air rates.


WASTE SLUDGE
DILUTED ANAEROBIC SUPERNATANT
PRIMARY CLARIFIER
CONTACT BASIN
STABILIZATION BASIN
SECONDARY CLARIFIER
MIXED LIQUOR
RAW SEWAGE
WASTE ACTIVATED SLUDGE
EFFLUENT
SETTLED SEWAGE
RETURN ACTIVATED SLUDGE
STABILIZATION BASIN
WASTE SLUDGE
PRIMARY CLARIFIER
CONTACT BASIN
SECONDARY CLARIFIER

PLANT FLOW DIAGRAM

```
                    VILLAGE OF RIDGEWOOD, NEW JERSEY
                         CONTACT STABILIZATION
                    CURRENT PLANT IN OPERATION - 1966

          PLANT FLOW                                    PLANT DESIGN

                      DESIGN     TYPICAL       AERATION BASINS         CLARIFIERS

  AVG DRY WEATHER,MGD   5.0        3.0         NUMBER          1       NUMBER              2
  MAX DAY,MGD           7.5        4.0         VOLUME,         0.      DIAMETER,FT        75.
  PEAK HOUR,MGD         7.5        6.0         CU FT      81,300.      DEPTH,FT          10.6
  % INDUSTRIAL                    50.                                  AREA-EACH,SF     4418.
                                                                       WEIR LENGTH,FT    424.
                                                                       WEIR TYPE     V-NOTCHE
                                                                       SLUDGE REMOVAL    PLOW
                                               AERATION SYSTEM

                                               SYSTEM       DIFFUSED
                                               TYPE             SOCK
                                               MAX SCFM     6000.
                                               AVG SCFM     1800.

          PLANT LOADING                                 PLANT PERFORMANCE

AERATION BASINS                 DESIGN      TYPICAL                       DESIGN    TYPICAL

  INF BOD5,MG/L                   135.        135.       EFF BOD5,MG/L     15.0      14.0
  INF SS,MG/L                      85.         85.       % BOD5 REMOVAL    90.       90.
  F/M,LB BOD5 REM/LB MLVSS/DAY     0.58        0.33      EFF SS,MG/L       10.0      10.0
  MCRT,DAYS                        0.          6.3       % SS REMOVAL      90.       88.
  SLUDGE AGE,DAYS                  0.4         5.0       SVI,ML/GRAM                100.
  MLSS,MG/L                      2000.       2100.       SDI,GRAM/100ML               1.00
  MAX MLSS,MG/L                              2300.
  MIN MLSS,MG/L                              1800.
  % VOLATILE                                   85.
  D.O. LEVELS,MG/L                 2.0         1.5
  AIR APPLIED,SCF/GAL                          0.9
  AIR APPLIED,SCF/LB BOD5 REM                856.
  RETURN, %                       43.          43.
  MAX RETURN, %                    0.
  DET. TIME,@ AVG FLOW,HOURS       2.9         4.9
  DET. TIME,@ A.F.+RETURN,HOURS    2.3         3.4
  DET. TIME,@ M.F.+RETURN,HOURS    1.7         2.8

SECONDARY CLARIFIERS                 DESIGN                  TYPICAL
                                 MAX DAY      AVG        MAX DAY      AVG

  SURFACE LOADING,GAL/SF/DAY      849.        566.        849.        340.
  WEIR LOADING,GAL/FT/DAY        8844.       5896.       4717.       3538.
  DETENTION TIME,HOURS              2.2         3.4         4.2         5.6
  SOLIDS LOADING,LBS/SF/HOUR        0.69        0.50        0.44        0.36
```

ST. PAUL, MINNESOTA - METROPOLITAN WASTEWATER TREATMENT PLANT

General Description

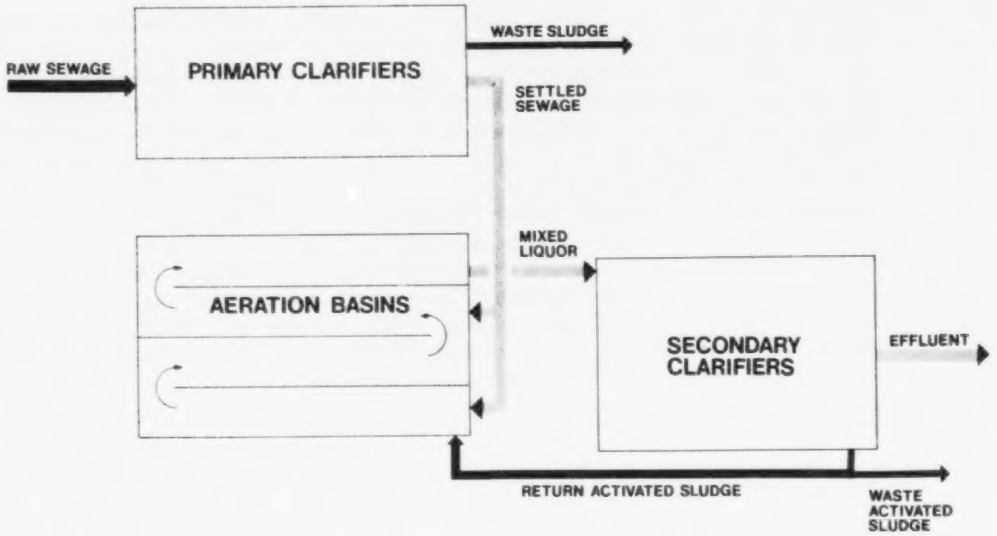
The current facilities were designed to operate as a high rate activated sludge process or step aeration activated sludge process, depending on influent conditions of the plant. Design average dry weather flow influent conditions are 218 mgd, 250 mg/l BOD, and 315 mg/l suspended solids.

This plant presently operates at or in excess of its design capacity. Existing sludge disposal facilities are also operating at design capacity. These factors combined result in the plant failing to meet effluent standards.

Performance

Probably one of the most serious problems with the plant is its inability to operate in the step aeration mode. The inability is due to (1) the loss of the incremental feed pipes, and (2) not enough air capacity.

Another problem which directly relates to the aerobic process is the fact that the gravity thickeners operate under an overloaded condition. This results in poor capture efficiencies in the thickeners and consequently adds a solids burden on the aeration system. Related to the above is the problem that more solids handling inventory capacity is required in the secondary system and flexibility for process control is very limited.


RAW SEWAGE
PRIMARY CLARIFIERS
WASTE SLUDGE
SETTLED SEWAGE
AERATION BASINS
MIXED LIQUOR
SECONDARY CLARIFIERS
EFFLUENT
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE

PLANT FLOW DIAGRAM

```
                CITY OF ST. PAUL, MINNESOTA - METROPOLITAN PLANT
                        CONVENTIONAL ACTIVATED SLUDGE
                       CURRENT PLANT IN OPERATION - 1974

            PLANT FLOW                                        PLANT DESIGN

                         DESIGN        TYPICAL        AERATION BASINS          CLARIFIERS

  AVG DRY WEATHER,MGD    218.0          230.0         NUMBER            8      NUMBER             12
  MAX DAY,MGD            322.0          345.0         LENGTH,FT       375.     LENGTH,FT         262.
  PEAK HOUR,MGD          391.0          460.0         WIDTH,FT        120.     WIDTH,FT           75.
  % INDUSTRIAL                           33.          DEPTH,FT         15.0    DEPTH,FT           11.0
                                                      AREA-EACH,SF  45000.     AREA-EACH,SF    19650.
                                                                               WEIR LENGTH,FT    829.
                                                                               WEIR TYPE       V-NOTCH
            PLANT LOADING                             AERATION SYSTEM          SLUDGE REMOVAL     PLOW

AERATION BASINS                     DESIGN        TYPICAL    SYSTEM       DIFFUSED
                                                             TYPE          SPARGER
    INF BOD5,MG/L                    188.          160.      MAX SCFM     80000.
    INF SS,MG/L                      122.          110.      AVG SCFM     60000.
    F/M,LB BOD5 REM/LB MLVSS/DAY       0.60          0.54
    MCRT,DAYS                          0.            4.8
    SLUDGE AGE,DAYS                    2.5           2.4
    MLSS,MG/L                       3000.         1500.
    MAX MLSS,MG/L                                  800.
    MIN MLSS,MG/L                                 2200.
    % VOLATILE                                      86.                     PLANT PERFORMANCE
    D.O. LEVELS,MG/L                   2.0           1.5
    AIR APPLIED,SCF/GAL                              1.0                              DESIGN     TYPICAL
    AIR APPLIED,SCF/LB BOD5 REM                    977.
    RETURN, %                         16.           17.          EFF BOD5,MG/L          32.0       37.0
    MAX RETURN, %                     49.                        % BOD5 REMOVAL         83.        77.
    DET. TIME,@ AVG FLOW,HOURS         4.4           4.2         EFF SS,MG/L            31.0       38.0
    DET. TIME,@ A.F.+RETURN,HOURS      3.8           3.6         % SS REMOVAL           75.        65.
    DET. TIME,@ M.F.+RETURN,HOURS      2.7           2.5         SVI,ML/GRAM                      110.
                                                                 SDI,GRAM/100ML                     0.91

SECONDARY CLARIFIERS                 DESIGN                    TYPICAL
                                MAX DAY      AVG          MAX DAY      AVG

    SURFACE LOADING,GAL/SF/DAY   1366.       925.          1366.       975.
    WEIR LOADING,GAL/FT/DAY     32368.     21914.         34680.     23120.
    DETENTION TIME,HOURS           1.4        2.1            1.3        2.0
    SOLIDS LOADING,LBS/SF/HOUR     1.59       1.13           0.85       0.59
```

SAN PABLO SANITARY DISTRICT, CALIFORNIA

General Description

The San Pablo Sanitary District, California operates a 12.5 mgd wastewater treatment plant designed for year-round complete nitrification. The original plant consisted of a primary treatment plant with effluent chlorination and anaerobic digestion for solids processing. Additions completed in 1972 included additional primary treatment facilities, a new plastic media roughing trickling filter, new aeration-nitrification tanks, new secondary clarifiers, an additional chlorine contact tank, new dissolved air flotation thickener, and two new anaerobic digesters. A primary design consideration in laying out the plant for nitrification was the presence of a significant volume fraction (11 to 13 percent) of potentially toxic industrial wastes in the influent wastewater. Tank truck washing residues and the waste from a manufacturer of organic peroxide and phenol formaldehyde are the major industrial waste sources. The roughing filter is used in the treatment plant to protect the nitrifying organisms from influent wastewater toxicity. Toxic dumps have caused severe sloughing and loss of growth on the media in the roughing filter, but nitrification remained unaffected.

Performance

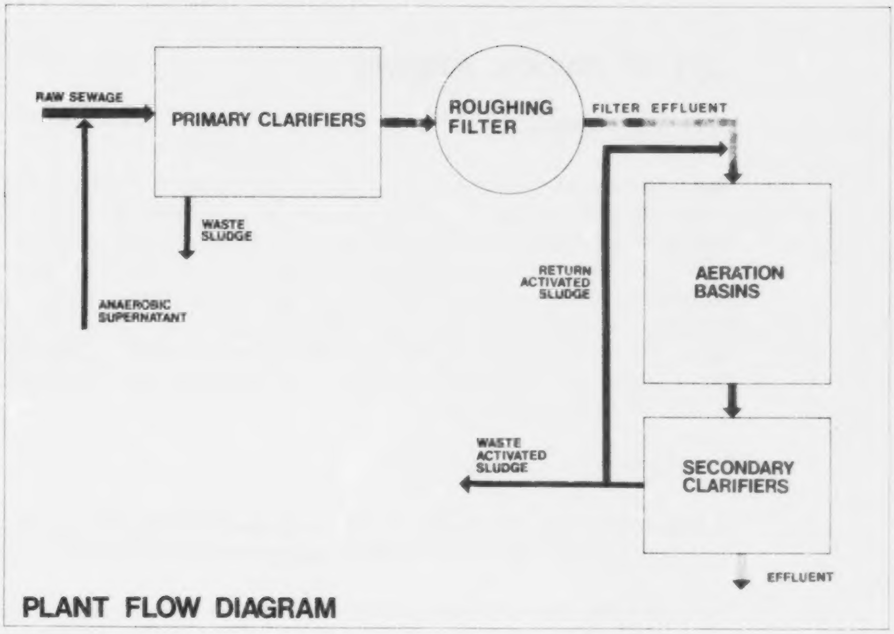
Effluent BOD_5 and suspended solids concentrations are typically 5 mg/l. Complete nitrification is obtained year round with a secondary effluent ammonia nitrogen concentration of less than 0.2 mg/l. The roughing filter converts influent organic matter to biological organisms. This is indicated by data which shows that the total BOD_5 and total COD remain relatively unaffected by the roughing filter operation while the soluble BOD_5 and soluble COD are reduced with a corresponding increase in total suspended solids.

Process Control

Control of the process is by maintaining an F/M of 0.15 lb BOD_5/lb MLVSS or an MCRT of around 13 days. The MLVSS concentration is checked each day and the waste rate is adjusted to give desired MLVSS concentration range based on desired F/M and previous months BOD and flow data.

Air rates are adjusted twice a day to maintain DO of 3.0 mg/l in aerator effluent. A timer is used to shut-off one blower at night.

RAS is controlled using a program cam in proportion to flow. The RAS flow is then modified by a ratio station to give approximately 5,000 mg/l solids in return.


RAW SEWAGE
PRIMARY CLARIFIERS
ROUGHING FILTER
FILTER EFFLUENT
WASTE SLUDGE
ANAEROBIC SUPERNATANT
RETURN ACTIVATED SLUDGE
AERATION BASINS
WASTE ACTIVATED SLUDGE
SECONDARY CLARIFIERS
EFFLUENT

PLANT FLOW DIAGRAM

CITY OF SAN PABLO, CALIFORNIA
CONVENTIONAL ACTIVATED SLUDGE WITH ROUGHING FILTER
CURRENT PLANT IN OPERATION - 1972

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	12.0	6.5
MAX DAY,MGD	16.5	15.5
PEAK HOUR,MGD	16.5	19.5
% INDUSTRIAL	-	15.

PLANT LOADING

TRICKLING FILTERS	DESIGN	TYPICAL
INF BOD5,MG/L	130.	120.
INF SS,MG/L	130.	120.
ORG LOAD,LBBOD5/1000CF/DAY	350.	170.
HYD LOAD, MGD/ACRE	840.	453.
RECIRCULATION,%	240.	240.

AERATION BASINS	DESIGN	TYPICAL
INF BOD5,MG/L	110.	100.
INF SS,MG/L	110.	100.
F/M,LB BOD5 REM/LB MLVSS/DAY	0.30	0.17
MCRT,DAYS	7.0	24.1
SLUDGE AGE,DAYS	3.0	7.4
MLSS,MG/L	1500.	1700.
MAX MLSS,MG/L		2000.
MIN MLSS,MG/L		1400.
% VOLATILE		75.
D.O. LEVELS,MG/L	2.0	3.0
AIR APPLIED,SCF/GAL		2.4
AIR APPLIED,SCF/LB BOD5 REM		3044.
RETURN, %	55.	31.
MAX RETURN, %	128.	
DET. TIME,@ AVG FLOW,HOURS	5.7	10.4
DET. TIME,@ A.F.+RETURN,HOURS	4.3	8.0
DET. TIME,@ M.F.+RETURN,HOURS	3.4	3.9

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	764.	556.	764.	301.
WEIR LOADING,GAL/FT/DAY	34375.	25000.	32292.	13542.
DETENTION TIME,HOURS	1.9	2.6	2.0	4.8
SOLIDS LOADING,LBS/SF/HOUR	0.49	0.38	0.48	0.23

PLANT DESIGN

AERATION BASINS	
NUMBER	2
LENGTH,FT	252.
WIDTH,FT	50.
DEPTH,FT	15.0
AREA-EACH,SF	12600.

AERATION SYSTEM	
SYSTEM	DIFFUSED
TYPE	SPARGER
MAX SCFM	24000.
AVG SCFM	11000.

CLARIFIERS	
NUMBER	2
LENGTH,FT	180.
WIDTH,FT	60.
DEPTH,FT	9.0
AREA-EACH,SF	10800.
WEIR LENGTH,FT	240.
WEIR TYPE	V-NOTCH
SLUDGE REMOVAL	FLIGHT

TRICKLING FILTERS	
NUMBER	1
DIAMETER,FT	52.
DEPTH,FT	18.0
AREA-EACH,SF	2124.
VOL-EACH,CF	38227.

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	11.0	4.0
% BOD5 REMOVAL	91.	97.
EFF SS,MG/L	11.0	3.0
% SS REMOVAL	91.	97.
SVI,ML/GRAM		100.
SDI,GRAM/100ML		1.00

CITY OF TUSCON, ARIZONA

General Description

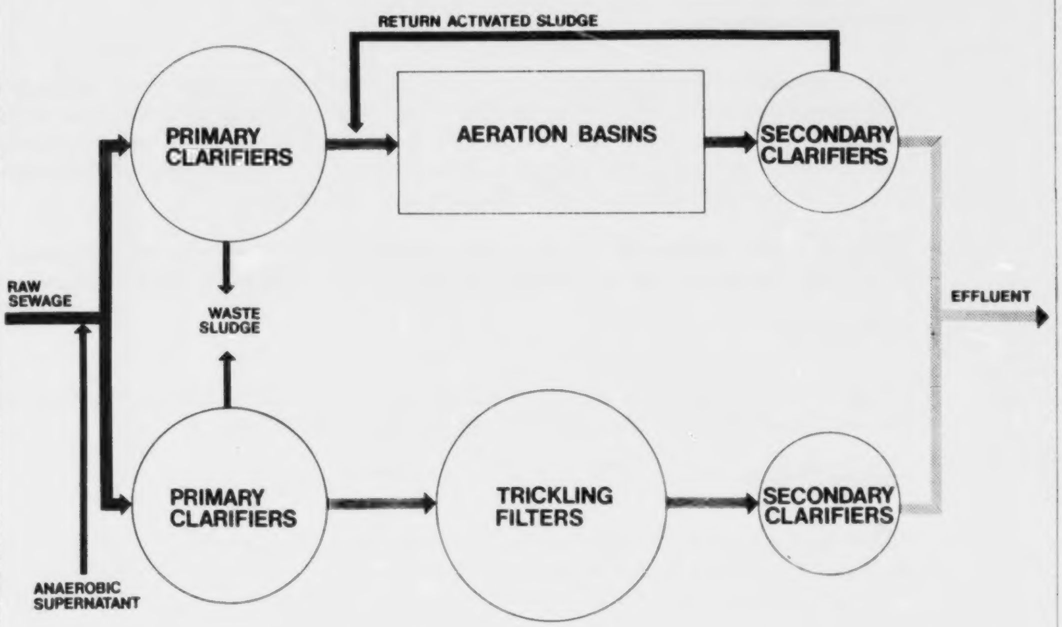
The first primary treatment plant was constructed in 1928 and expanded in 1942. Primary effluent was used for irrigation. In 1951 the first 12 mgd activated sludge plant was put into operation, secondary effluent being sold for irrigation. In 1960 a high-rate trickling filter plant was added in parallel to the existing activated sludge plant, increasing total capacity to 24 mgd. A second activated sludge plant was placed in operation in 1968, in parallel with the other two plants. With the addition of this third plant, the total treatment capacity was increased to 37 mgd. At the present time, the three plants are treating in excess of 33 mgd, but the plants are hydraulically overloaded 12-18 hours per day.

Performance and Process Control

The two activated sludge plants are basically conventional plug flow processes. There is not enough flexibility in the plant to make other modes of operation feasible.

The plants are operated with a low MLSS, under 1,000 to prevent frothing from becoming a problem. The sludge age is kept to 1.5 - 2 days to control frothing problems. The activated sludge processes are controlled to sludge age and MLSS. Wasting and return rates are adjusted as needed to control to the appropriate sludge age and MLSS.

Operations are not significantly affected by changes in weather or other environmental changes. The erratic flow characteristics, which hydraulically overload the plant for 12 - 18 hours per day, cause the most serious chronic operational problems for the operators. There is a solids washout problem in the secondaries when the hydraulic overload condition exists.


RETURN ACTIVATED SLUDGE
PRIMARY CLARIFIERS
AERATION BASINS
SECONDARY CLARIFIERS
RAW SEWAGE
WASTE SLUDGE
EFFLUENT
PRIMARY CLARIFIERS
TRICKLING FILTERS
SECONDARY CLARIFIERS
ANAEROBIC SUPERNATANT

PLANT FLOW DIAGRAM

```
                          CITY OF TUCSON, ARIZONA - PLANT #3
                             CONVENTIONAL ACTIVATED SLUDGE
                           CURRENT PLANT IN OPERATION - 1968

              PLANT FLOW                                          PLANT DESIGN

                            DESIGN       TYPICAL      AERATION BASINS            CLARIFIERS

   AVG DRY WEATHER,MGD       13.0         12.4        NUMBER            4        NUMBER             2
   MAX DAY,MGD               14.0         14.0        LENGTH,FT         0.       DIAMETER,FT      105.
   PEAK HOUR,MGD             22.0         22.0        WIDTH,FT          0.       DEPTH,FT          10.0
   % INDUSTRIAL                           50.         DEPTH,FT          0.       AREA-EACH,SF    8659.
                                                      AREA-EACH,SF      0.       WEIR LENGTH,FT   330.
                                                                                 WEIR TYPE      V-NOTCH
              PLANT LOADING                                                      SLUDGE REMOVAL  VACUUM
                                                      AERATION SYSTEM

AERATION BASINS                      DESIGN       TYPICAL
                                                      SYSTEM         DIFFUSED
   INF BOD5,MG/L                      150.         149.   TYPE            SPARGER
   INF SS,MG/L                        100.         87.    MAX SCFM       10000.
   F/M,LB BOD5 REM/LB MLVSS/DAY         0.40         0.71 AVG SCFM        8100.
   MCRT,DAYS                          0.           2.5
   SLUDGE AGE,DAYS                    4.4          2.7
   MLSS,MG/L                         2000.        1100.
   MAX MLSS,MG/L                                  1400.
   MIN MLSS,MG/L                                   500.
   % VOLATILE                                       77.                   PLANT PERFORMANCE
   D.O. LEVELS,MG/L                   2.0          3.0
   AIR APPLIED,SCF/GAL                             0.9
   AIR APPLIED,SCF/LB BOD5 REM                    888.                             DESIGN     TYPICAL
   RETURN, %                          31.          30.
   MAX RETURN, %                      58.                     EFF BOD5,MG/L          15.0       22.0
   DET. TIME,@ AVG FLOW,HOURS         4.8          5.0        % BOD5 REMOVAL         90.        85.
   DET. TIME,@ A.F.+RETURN,HOURS      3.7          3.9        EFF SS,MG/L            10.0       21.0
   DET. TIME,@ M.F.+RETURN,HOURS      3.5          3.5        % SS REMOVAL           90.        76.
                                                              SVI,ML/GRAM                      235.
                                                              SDI,GRAM/100ML                     0.43

SECONDARY CLARIFIERS                   DESIGN                      TYPICAL
                                  MAX DAY       AVG          MAX DAY      AVG

   SURFACE LOADING,GAL/SF/DAY      808.         751.          808.        716.
   WEIR LOADING,GAL/FT/DAY        21212.       19697.        21212.      18788.
   DETENTION TIME,HOURS              2.2          2.4           2.2         2.5
   SOLIDS LOADING,LBS/SF/HOUR        0.72         0.68          0.39        0.36
```

NORTHWEST BERGEN CO. SEWER AUTHORITY, WALDWICK NEW JERSEY

General Description

The wastewater treatment plant a conventional activated sludge plant utilizing the step feed aeration mode of operation. Diffused spiral roll aeration is provided by positive displacement blowers. MLSS is settled in rectangular clarifiers with sludge withdrawal from a trough at the midpoint of each tank. Waste solids are transferred to gravity thickeners followed by centrifucation and incineration.

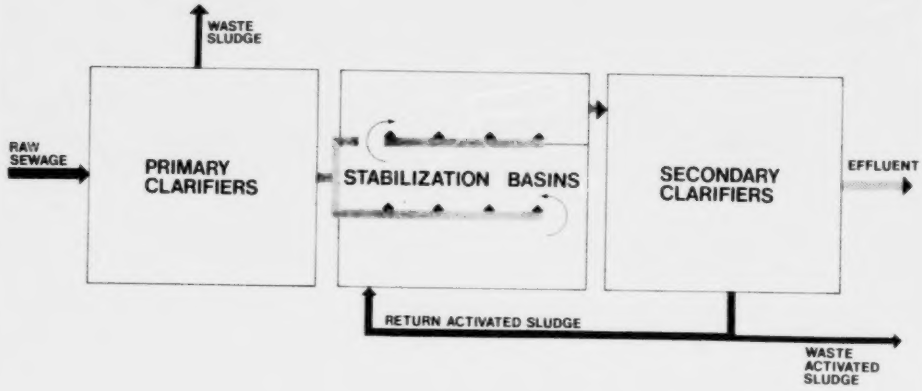
The plant treats wastewater primarily from domestic sources with an average daily flow of 4.6 mgd. Design average dry weather flow is 8.5 mgd. Effluent is discharged to a river.

Performance

Effluent concentrations of BOD and suspended solids are typically less than 5 mg/l. Settled wastewater has a typical BOD concentration of 100 mg/l.

Process Control

F/M is held around 0.13 to 0.25 lbs BOD/day/lb MLSS. Actual wasting is controlled to maintain a constant MCRT of about 6 days. The mode of process control is by maintaining a constant MCRT which varies the MLSS and F/M. D.O. is maintained around 4.0 mg/l.


WASTE SLUDGE
RAW SEWAGE
PRIMARY CLARIFIERS
STABILIZATION BASINS
SECONDARY CLARIFIERS
EFFLUENT
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE

PLANT FLOW DIAGRAM

CITY OF WALDWICK, NEW JERSEY - NE BERGEN CO. PLANT
CONTACT STABILIZATION
CURRENT PLANT IN OPERATION - 1975

PLANT FLOW

	DESIGN	TYPICAL
AVG DRY WEATHER,MGD	8.5	4.6
MAX DAY,MGD	21.0	8.0
PEAK HOUR,MGD	25.0	25.0
% INDUSTRIAL		50.

PLANT DESIGN

AERATION BASINS		CLARIFIERS	
NUMBER	3	NUMBER	3
LENGTH,FT	205.	LENGTH,FT	160.
WIDTH,FT	20.	WIDTH,FT	32.
DEPTH,FT	15.0	DEPTH,FT	10.0
AREA-EACH,SF	4100.	AREA-EACH,SF	5120.
		WEIR LENGTH,FT	384.
		WEIR TYPE	V-NOTCH
		SLUDGE REMOVAL	VACUUM

AERATION SYSTEM

SYSTEM	DIFFUSED
TYPE	SOCK
MAX SCFM	19050.
AVG SCFM	3800.

PLANT LOADING

AERATION BASINS	DESIGN	TYPICAL
INF BOD5,MG/L	275.	116.
INF SS,MG/L	275.	80.
F/M,LB BOD5 REM/LB MLVSS/DAY	1.10	0.28
MCRT,DAYS	0.	4.7
SLUDGE AGE,DAYS	1.2	6.8
MLSS,MG/L	2000.	1800.
MAX MLSS,MG/L		2000.
MIN MLSS,MG/L		1500.
% VOLATILE		75.
D.O. LEVELS,MG/L	2.0	4.5
AIR APPLIED,SCF/GAL		1.2
AIR APPLIED,SCF/LB BOD5 REM		1274.
RETURN, %	85.	18.
MAX RETURN, %	85.	
DET. TIME,@ AVG FLOW,HOURS	3.9	7.2
DET. TIME,@ A.F.+RETURN,HOURS	2.7	6.1
DET. TIME,@ M.F.+RETURN,HOURS	1.3	3.8

SECONDARY CLARIFIERS	DESIGN		TYPICAL	
	MAX DAY	AVG	MAX DAY	AVG
SURFACE LOADING,GAL/SF/DAY	1367.	553.	1367.	299.
WEIR LOADING,GAL/FT/DAY	18229.	7378.	6944.	3993.
DETENTION TIME,HOURS	1.3	3.2	3.4	6.0
SOLIDS LOADING,LBS/SF/HOUR	1.13	0.56	0.36	0.22

PLANT PERFORMANCE

	DESIGN	TYPICAL
EFF BOD5,MG/L	20.0	4.0
% BOD5 REMOVAL	95.	97.
EFF SS,MG/L	20.0	4.0
% SS REMOVAL	95.	95.
SVI,ML/GRAM		258.
SDI,GRAM/100ML		0.39

APPENDIX C - LABORATORY EQUIPMENT

Outlined on the following pages are suggested laboratory equipment, supplies and chemical reagents required to perform the process control tests for typical aerobic biological treatment facilities.

In addition, optional equipment, and/or methods have been included for certain tests. All test methods are referenced to "Standard Methods for the Examination of Water and Wastewater," 14th Edition, 1976, APHA, AWWA, WPCF.

Additional equipment required in conjunction with the following tests include:

1. Standard type refrigeration for sample storage
2. Fume hood
3. Bottles for collecting and storing of samples or use with automatic samplers.
4. An appropriate carrying device for sample bottles if samples are collected manually
5. Sample bottle tongs with extended handle

BOD TEST

A. Equipment and supplies

1. Incubator (BOD) Capacity, 13 cu. ft., ambient air thermostatically controlled at 20 ± 1° C
2. Bottles (BOD), meet APHA specifications, numbered in sequence, 300 ml capacity, 2 cases (48 bottles suggested)
3. Buret, Straight Stopcock, with side tube stopcock for filling, 50 ml capacity, 0.1 ml subdivisions
4. Support, Buret Double, with holder
5. Bottle, reagent, 1000 ml capacity, with tubulature near bottom
6. Bottles (4), Dropping Assembly, 250 ml capacity
7. Bottle, carboy, 5 gal
8. Tubing, polyethylene, 10 ft.
9. Pipets, volumetric, assorted sizes, 1 to 25 ml, color coded, 0.1 ml subdivisions
10. Balance, Triple Beam, 600 grams, sensitivity 0.1 gram
11. Hot Plate/Magnetic Stirrer
12. Flasks erlenmeyer, 500 ml capacity

B. Chemical Reagents

1. Distilled water
2. Sodium Thiosulfate solution
3. Concentrated Sulfuric Acid
4. Manganous Sulfate solution
5. Alkaline iodide-sodium azide solutions
6. Starch solution
7. Phosphate buffer solution
8. Magnesium Sulfate solution
9. Calcium Chloride solutions
10. Ferric Chloride solution

C. Optional Equipment/Method
   1. Polargraphic Dissolved Oxygen Meter, self contained, with BOD agitator and probe assembly

COD TEST

A. Equipment and Supplies
   1. Extraction Apparatus, 6 unit, complete with support rods, clamping brackets, and rod clamps, 115 Volt ac
   2. Condensers, reflux with \$ ground joint both top and bottom, and drip tip at bottom, length 350 mm
   3. Flasks, boiling, flat bottom, short neck, with \$ joint, 250 ml capacity
   4. Cylinder, graduated, 50 ml capacity
   5. Pipet Filler, Polypropylene, Nalgene, safety, for use with volatile, corrosive and poisonous liquids
   6. Pipets, Volumetric, color coded, 25 ml capacity, 0.1 ml subdivisions
   7. Tubing, polyethylene, 25 ft.
   8. Buret, Straight Stopcock, with side tube stopcock for filling, 50 ml capacity, 0.1 ml subdivisions
   9. Support, Buret Double, with holder
   10. Bottle, Reagent, 1000 ml capacity, with tabulature near bottom
   11. Potable water source
   12. Rubber gloves and apron
   13. Clamp, Flask, Safety Tongs
   14. Safety glasses
   15. Beads, glass
   16. Balance, Triple Beam, 600 grams, sensitivity 0.1 gram

B. Chemical Reagents
   1. Standard Potassium Dichromate Solution
   2. Sulfuric Acid-Silver Sulfate Solution
   3. Standard Ferrous Ammonium Sulfate Solution
   4. Ferroin Indicator
   5. Silver Sulfate, powder
   6. Mercuric Sulfate, analytical grade crystals

SUSPENDED SOLIDS TEST

I. TOTAL SUSPENDED SOLIDS
   A. Equipment and Supplies
      1. Filter, holders, membrane assembly for vacuum filtration
      2. Flasks, filtering, 1000 ml capacity
      3. Tubing, Vacuum, 10 ft.
      4. Forceps, specimen
      5. Pump, Air Pressure and vacuum type
      6. Paper, filter, glass fiber, 47 mm diameter

7. Vacuum, manifold with four connections and stopcocks
8. Oven, drying, with forced draft; thermostatically controlled to maintain 103 ± °C
9. Cabinet, Desiccator, for vacuum drying and storage
10. Balance, Analytical, automatic, digital, single pan; readout to 0.1 milligram
11. Cylinder, graduated, assorted sizes (25 to 100 ml capacity)

B. Chemicals
   1. Desiccant, silica gel air dryer

II. VOLATILE SUSPENDED SOLIDS

A. Equipment and Supplies
   1. Furnace, muffle, 115 Volt ac; thermostatically controlled to maintain 600 ± °C

III. OPTIONAL EQUIPMENT/METHOD

A. Gooch crucible method with 2.4 cm glass fiber filter

SETTLEABLE SOLIDS TEST

A. Equipment and Supplies
   1. Cones, Imhoff, 1000 ml capacity
   2. Stand, Imhoff cone
   3. Rod, stirrer, glass
   4. Timer, interval, range 15 minutes to 2 hours, 115 Volt ac

NITROGEN-KJELDHAL (TKN)

A. -Equipment and Supplies
   1. Bulbs, connecting, spherical, 65 mm diameter
   2. Tubes, delivery, with safety bulb
   3. Flasks, 800 ml capacity
   4. Stopper, rubber, 800 ml Flask size
   5. Spectrophotometer, 400 to 425 mμ with light patch of 1 cm or longer
   6. Distillation Apparatus, 6 unit, Kjeldhal, 115 Volt ac
   7. Beads, glass
   8. Flasks, erlenmeyer, 500 ml capacity
   9. Cylinders, graduated, 50 to 500 ml capacity
   10. Balance, triple beam, 600 grams, sensitivity 0.1 gram
   11. Rubber gloves and apron
   12. Safety glasses

B. Chemical Reagents
   1. Distilled Water

2. Potassium Sulfate
3. Concentrated Sulfuric Acid
4. Red Mercuric Oxide
5. Phenophalien Indicator Solution
6. Sodium Hydroxide
7. Sodium Thiosulfate, 5 parts water
8. Methyl Red Indicator
9. Ethyl Alcohol
10. Methylene Blue
11. Indicating Boric Acid Solution

C. Optional Equipment/Method

1. Filter Photometer, with maximum transmittance at 400 to 425 mμ and light path of 1 cm or longer
2. Nessler Tubes, matched, 50 ml capacity, tall form

AMMONIA - NITROGEN TEST

(Nesslerization Method)

A. Equipment and Supplies

1. Spectrophotometer for use at 400 to 500 mμ and light path of 1 cm or longer
2. Beakers, assorted sizes, 25 to 200 ml
3. Pipet, fillers, for use with corrosive liquid
4. Pipets, assorted sizes, 1 to 25 ml, color coded, 0.1 ml subdivisions
5. Cylinders, graduated, assorted sizes 25 to 200 ml
6. Bottles, reagent, 1000 ml capacity
7. Balance, triple beam, 600 grams, sensitivity 0.1 gram
8. Rubber gloves and apron
9. Safety glasses

B. Chemical Reagents

1. Ammonia free water
2. Potassium Dihydrogen Phosphate
3. Dipotassium Hydrogen Phosphate
4. Dechlorination agent - Thiosulfate
5. Sodium Hydroxide, 0.3N
6. Sodium Arsenite
7. Sodium Sulfite
8. Sulfuric Acid
9. Zinc Sulfate
10. Mercuric Iodide
11. Potassium Iodide
12. Ammonium Chloride, Anhydraus
13. Hydrochloric Acid
14. Potassium Chloroplatinate
15. Cobaltous Chloride

C. Optional Equipment/Method
   1. Filter Photometer with maximum transmittance at 400 to 425 mμ lightpath of 1 cm or longer
   2. Nessler Tubes, matched, 50 ml, tall form
   3. pH meter, equipped with high pH electrode
   4. Phenate Method (Tentative)

NITRITE - NITROGEN TEST

A. Equipment and Supplies
   1. Spectrophotometer, for use at 400 to 500 mμ and light path of 1 cm or longer
   2. Beakers, assorted sizes, 25 to 200 ml
   3. Pipet, fillers, for use with corrosive liquids
   4. Pipets, assorted sizes, 1 to 25 ml, color coded, 0.1 ml subdivisions
   5. Cylinders, graduated, assorted sizes, 25 to 200 ml
   6. Bottles, reagent, 1,000 ml capacity
   7. Balance, Triple Beam, 600 grams, sensitivity 0.1 gram
   8. Rubber Gloves and Apron
   9. Safety Glasses

B. Chemical Reagents
   1. Nitrite-Free Water
   2. Potassium Permanganate
   3. Calcium Hydroxide
   4. Orthotolidine
   5. Concentrated Sulfuric Acid
   6. Manganese Sulfate
   7. Ammonium Oxalate
   8. EDTA Reagent
   9. Sulfanilis Acid
   10. Hydrochloric Acid
   11. Naphthylamine Hydrochloride
   12. Sodium Acetate
   13. Sodium Nitrite

C. Optional Equipment/Method
   1. Filter Photometer, with maximum transmittance near 500 mμ and light path of 1 cm or longer
   2. Nessler Tubes, matched, 50 ml, tall form

NITRATE - NITROGEN TEST
(Brucine Method)

A. Equipment and Supplies
   1. Spectrophotometer, for use at 400 to 500 mμ and light path of 1 cm or longer
   2. Beakers, assorted sizes, 25 to 200 ml
   3. Pipet, fillers, for use with corrosive liquids
   4. Pipets, assorted sizes, 1 to 25 ml, color coded, 0.1 ml subdivisions

5. Cylinders, graduated, assorted sizes, 25 to 200 ml
6. Bottles, reagent, 1,000 ml capacity
7. Balance, Triple Beam, 600 grams, sensitivity 0.1 gram
8. Rubber Gloves and Apron
9. Safety Glasses
10. Test Tube Rack
11. Test Tubes, 2.5 x 15 cm

B. Chemical Reagents

1. Potassium Nitrate, anhydrous
2. Sodium Arsenite
3. Brucine Sulfate
4. Sulfanilic Acid
5. Concentrated Hydrochloric Acid
6. Concentrated Sulfuric Acid
7. Sodium Chloride

C. Optional Equipment/Method

1. Filter Photometer, with violet filter, having maximum transmittance between 400-425 mμ and light path of 1 inch
2. Zinc Reduction Method
3. Cadmium Reduction Method
4. Phenoldisulfanic Acid Method
5. Chromotropic Acid Method

TOTAL PHOSPHORUS (AS P)

(Ascorbic Acid Method)

A. Equipment and Supplies

1. Spectrophotometer, for use at 400 to 500 mμ and light path of 1 cm or longer
2. Beakers, assorted sizes, 25 to 200 ml
3. Pipet, fillers, for use with corrosive liquids
4. Pipets, assorted sizes, 1 to 25 ml, color coded, 0.1 ml subdivisions
5. Cylinders, graduated, assorted sizes, 25 to 200 ml
6. Bottles, reagent, 1,000 ml capacity
7. Balance, Triple Beam, 600 grams, sensitivity 0.1 gram
8. Rubber Gloves and Apron
9. Safety Glasses
10. Cylinder, mixing 100 ml capacity
11. Hot Plate/Magnetic Stirrer, combination

B. Chemical Reagents

1. Ascorbic Acid
2. Antimon Potassium Tartrate
3. Hyrochloric Acid
4. Sulfuric Acid
5. Ammonium Malybdate

6. Ammonium Persulfate
7. Potassium Phosphate, dibasic
8. Potassium Phosphate, monobasic
9. Sodium Hydroxide
10. Phenolphthalein

C. Optional Equipment/Method
   1. Filter Photometer, with red color filter and light path of 0.5 cm or longer
   2. Vanadamolybdaphasphoric Acid Colorimetric Method
   3. Stannous Chloride Method

30-MINUTE SETTLING TEST

(One Liter Graduated Cylinder Method)

A. Equipment and Supplies
   1. Cylinders, graduated, one liter (1,000 ml) capacity; glass cylinders recommended.
   2. Rod, glass, stirrer
   3. Interval Timer, 1 minute to 2 hours, 115 volt ac
   4. Bottles, sample, wide mouth, 1 gallon capacity

B. Optional Equipment/Method
   1. Mallory Direct Reading Settlometer, 2,000 ml capacity

DISSOLVED OXYGEN TEST

(Winkler Method)

A. Equipment and Supplies
   1. Bottles (BOD), meet APHA specifications, numbered in sequence, 300 ml capacity, 2 cases (48 bottles suggested)
   2. Buret, straight stopcock, with side tube stopcock for filling, 50 ml capacity, 0.1 ml subdivisions
   3. Support, Buret Double, with holder
   4. Bottle, reagent, 1,000 ml capacity, with tubulature near bottom
   5. Bottles (4), dropping assembly, 250 ml capacity
   6. Tubing, polyethylene, 10 ft.
   7. Pipets, volumetric assorted sizes, 1 to 25 ml, color coded, 0.1 ml subdivisions
   8. Balance, Triple Beam, 600 grams, sensitivity 0.1 gram
   9. Hot Plate/Magnetic Stirrer
   10. Flasks, erlenmeyer, 500 ml capacity

B. Chemical Reagents
   1. Distilled Water
   2. Sodium Thiosulfate Solution
   3. Concentrated Sulfuric Acid
   4. Manganous Sulfate Solution
   5. Alkaline Iodide-Sodium Azide Solutions
   6. Starch Solution

7. Sulfamic Acid, technical grade
8. Copper Sulfate
9. Concentrated Acetic Acid

C. Optional Equipment/Method
   1. Polarographic Dissolved Oxygen Meter, self contained, with probe assembly

pH TEST
(Electrometric Method)

A. Equipment and Supplies
   1. pH Meter
   2. Electrode, reference
   3. Electrode, glass
   4. Beakers, 100 ml capacity
   5. Bottle, wash, 250 ml capacity
   6. Tissue Paper

B. Chemical Reagents
   1. Buffer Solution, pH 4.0
   2. Buffer Solution, pH 7.0
   3. Buffer Solution, pH 10.0
   4. Filling Solution, for reference electrode
   5. KCL Solution, saturated

C. Optional Equipment/Method
   1. Colorimetric Method (not recommended for wastewaters)
   2. pH Paper (provides quick estimate)

TEMPERATURE

A. Equipment and Supplies
   1. Combination Thermometers, – 20° to + 150° C, + 20° to 220° F
   2. Thermometer, 0° to + 120° C, with metal armored case and nylon cord

B. Optional Equipment/Method
   1. Telethermometer
   2. Thermistor Probe

REFERENCES

APHA, AWWA, WPCF, *Standard Methods for the Examination of Water and Wastewater*, 14th Edition, 1976 - APHA New York, N.Y.

Ministry of the Environment, *Activated Sludge Process Analyses and Interpretation Workshop Manual*, Training, Certification, and Safety Section, Toronto, Ontario, M4V, LP5.

Nagano, J., *Laboratory Procedures for Operators of Water Pollution Control Plants*, California Water Pollution Control Association, October 2, 1970.

U.S. Environmental Protection Agency, *Estimating Laboratory Needs for Municipal Wastewater Treatment Facilitiesm*, Office of Water Program Operations, Publication No. 4301 9-74-002, Washington, D.C.

U.S. Environmental Protection Agency, *Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities*, Office of Water Program Operations, Publication No. 4301 9-74-002, Washington, D.C.

Water Pollution Control Federation, *Simplified Laboratory Practices for Wastewater Examination*, Manual of Practice No. 18, 1971.

APPENDIX D - GLOSSARY

Absorption The taking up of one substance into the body of another.

Activated Sludge Sludge floc produced in raw or settled wastewater by the growth of organisms (including zoogleal bacteria) in the presence of dissolved oxygen. The term "activated" comes from the fact that the sludge is teaming with active, or living, microorganisms.

Activated Sludge Loading The pounds of biochemcial oxygen demand (BOD) in the applied liquid per unit volume of aeration capacity or per pound of activated sludge per day.

Activated Sludge Process A biological wastewater treatment process in which a mixture of wastewater and activated sludge is agitated and aerated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation and wasted or returned to the process [illegible]eded.

Adsorption The adherence of a gas, liquid, or dissolved material on the surface or interface zone of another substance.

Aeration The bringing about of intimate contact between air and a liquid by one or more of the following methods: (a) spraying the liquid in the air, (b) bubbling air through the liquid, and (c) agitating the liquid to promote surface absorption of air.

Aeration Period The theoretical time, usually expressed in hours, during which mixed liquor is subjected to aeration in an aeration tank while undergoing activated sludge treatment. It is equal to the volume of the tank divided by the volumetric rate of flow of the wastewater and return sludge.

Aerobic (1) A condition in which "free" or dissolved oxygen (O_2) is present. (2) Requiring, or not destroyed by, the presence of free oxygen.

Alkalinity Buffering, or acid neutralizing, capacity of water due primarily to its carbonate, bicarbonate, and hydroxide content.

Ambient Temperature Temperature of the surroundings.

Anaerobic (1) A condition in which "free" or dissolved oxygen (O_2) is *not* present. (2) Requiring, or not destroyed by, the absence of free oxygen.

Assimilation The process by which food is converted to cell protoplasm.

Autotrophic Having the ability to utilize CO_2 as sole source of carbon.

Available Oxygen The quantity of dissolved oxygen available for oxidation of organic matter in a water body.

Bacteria Singe celled microorganisms of primary importance in most biological wastewater treatment processes.

Batch Reactor Reactor in which flow is neither entering nor leaving on a continuous basis.

Biochemical Oxygen Demand (BOD) A standard test indicating the quantity of oxygen utilized by wastewater under controlled conditions of temperature and time.

Bioassay Estimating the toxicity of an effluent by testing its effects on living organisms.

Biodegradation The destruction or mineralization of organic materials by microorganisms.

Bioflocculation A condition whereby organic materials tend to be transferred from the dispersed form in wastewater to settleable material by mechanical entrapment and assimilation.

Biological Examinations A microscopic survey of the types of microorganisms present in a sample.

Biological Filter A bed of sand, gravel, broken stone, or other medium through which wastewater flows or trickles that depends on biological action for its effectiveness.

Biological Filtration The process of passing a liquid through a biological filter, thus permitting contact with zoogleal films attached to the media that adsorb and absorb fine suspended, collodial, and dissolved solids and release end products of biochemical oxidation.

Biological Wastewater Treatment Forms of wastewater treatment in which bacterial or biochemcial action is intensified to stablize the unstable organic matter present and remove non-settling solids. Intermittent sand filters, contact beds, trickling filters, and activated sludge processes are examples.

Biological Reactor The site(s) in a wastewater treatment plant where the principal biochemical reactions take place.

Biomass Active or dead microorganisms present in a particular area of a biological treatment plant.

BOD See Biochemical Oxygen Demand.

BOD$_5$ Five-day biochemcial oxygen demand; the oxygen demand exerted after five days of a BOD test. (See Biochemcial Oxygen Demand)

BOD Load The BOD content, usually expressed in pounds per unit of time, of wastewater passing into a waste treatment system.

Bulking Sludge An activated sludge that settles poorly because of low-density floc.

Carbonaceous Oxidation Biochemical process by which heterotrophic microorganisms derive energy from organic wastes, rendering more stable organics or inorganics as end-products.

Catalyst A substance that speeds up a chemical reaction without being altered itself.

Chemical Oxygen Demand (COD) A measure of the oxygen-consuming capacity of inorganic and organic matter present in wastewater. It is expressed as the equivalent amount of oxygen required as determined using a chemical oxidant in a standard test. It does not differentiate between stable and unstable organic material and thus does not necessarily correlate with biochemical oxygen demand (BOD).

Chlorination The application of chlorine or chlorine compounds to water or wastewater, usually for disinfection, but frequently to obtain other biological or chemical results.

Chlorine Contact Chamber A detention basin provided primarily to secure the diffusion of chlorine through the liquid.

Chlorine Demand The difference between the amount of chlorine added to water or wastewater and the amount of residual chlorine remaining at the end of a specified contact period.

Ciliate A type of protozoan characterized by short, filamentous cilia used for motility and/or capturing food.

Coagulation The clustering of suspended solids into larger particles or flocs caused by the addition of a chemical (coagulant) or by biological processes.

COD See Chemical Oxygen Demand.

Coliform-Group Bacteria A group of bacteria found in the intestines of man which are used as indicators of fecal pollution and the presence of pathogenic bacteria in water and wastewater.

Colloids Finely divided, non-settleable solids which may be removed by coagulation or biochemcial action.

Complete Mix Idealized continuous flow reactor in which fluid particles are immediately dispersed throughout the reactor.

Complete Treatment In an imprecise and general sense, the processing of domestic and some industrial wastewaters by means of primary and secondary treatment. It may include other specialized types of treatment and disinfection. A high percentage removal of suspended, colloidal, and dissolved organic matter is implied.

Composite Samples Samples collected at regular intervals, sometimes in proportion to the existing flow, and then combined to form a sample representative of flow over a period of time.

Concentration (1) The amount of a given substance dissolved or suspended in a unit volume of solution. (2) The process of increasing the solids per unit volume in a liquid.

Contact Aerator A biological unit consisting of stone, cement-asbestos, or other surfaces supported in an aeration tank, in which air is diffused up and around the surfaces and settled wastewater flows through the tank.

Contact Stabilization Process A modification of the activated sludge process in which wastewater is aerated with a high concentration of activated sludge for a short period, usually less than 60 minutes, to obtain BOD removal. The solids are subsequently separated by sedimentation and transferred to a stabilization tank where aeration is continued, starving the activated sludge before returning it to the aeration basin.

Conventional Activated Sludge Process Activated sludge process utilizing plug-flow through the aeration basin with primary effluent and activated sludge fed at the head end and uniform aeration throughout.

Cytoplasm Contents of a biological cell excluding the nucleus.

Degradation The conversion of a substance to simpler compounds.

Density Mass per unit volume of any substance.

Design Parameters Various criteria used to determine size, shape, quantity, and/or methods in the design of units and processes in a treatment plant.

Detention Time The time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank (volume divided by flow rate).

Dewater To extract a portion of the water present in a sludge or slurry.

Diffused Air Aeration The process by which air is compressed and discharged below the mixed liquor surface through some type of air diffusion device.

Diffuser A device (porous plate, tube, bag) used to break the air stream from a blower system into fine bubbles in a liquid.

Disinfection The process by which pathogenic (disease-causing) microorganisms are killed. Chlorination is the most frequently used method in wastewater treatment.

Dissolved Oxygen (DO) Molecular or "free" oxygen (O_2) dissolved in water or wastewater.

Dissolved Solids Very small, non-settling particles defined by the method of measurement (see Standard Methods).

Distributor A mechanical device used for spreading wastewater over the surface of a trickling filter. A rotary distributor is usually used.

Ditch Oxidation A modification of the activated sludge process or the aerated pond, in which the mixture under treatment is circulated in an endless ditch and aeration and circulation are produced by a mechanical device.

Diurnal Flow Flow that shows marked and regular variations through the course of a day.

Domestic Wastewater Wastewater derived principally from dwellings, business buildings, institutions and other non-industrial sources.

DO See Dissolved Oxygen.

Dosing Ratio The maximum rate of wastewater application to a filter divided by the average rate.

Dry Suspended Solids The weight of the suspended matter in wastewater or other liquid after drying for 1 hr. at 103° C.

Ecology The branch of biology dealing with the relationships between organisms and their environment.

Effluent Wastewater or other liquid flowing from a basin, treatment process, or treatment plant.

Enzymes Substances produced by living organisms that speed up chemical changes.

Endogenous Respiration Utilization internal cellular material as food under aerobic conditions when an adequate external food supply is unavailable.

Excess Activated Sludge The quantity of activated sludge above that needed for process operation.

Extended Aeration A modification of the activated sludge process utilizing very long aeration periods.

F/M Ratio Food to microorganism ratio; the amount of food (organic matter as BOD or COD) available per unit mass of microorganisms.

Facultative (1) A condition in which "free" or dissolved oxygen (O_2) is present only in some places. (2) Able to function both in the presence or absence of free oxygen.

Filamentous Bacteria Bacteria that grow in a thread or filamentous form.

Filter Flooding The filling of a trickling filter to an elevation above the top of the medium by closing all outlets, in order to control nuisance of filter flies.

Floc Groups or "clumps" of bacteria that have come together and formed a small gelatinous mass. Found in aeration tanks and secondary clarifiers.

Flocculation An action resulting in the gathering of fine particles to form larger particles.

Grab Sample A single sample of wastewater taken all at one time from one place.

Head A term used in expressing the pressure or energy of fluids in terms of the height of a verticle column of water.

Head Loss Energy lost, expressed in head, from flowing fluids due to friction and turbulence.

Heterotrophic A term describing organisms which use organics as the source of cell carbon.

High-Rate Filter A trickling filter operated at a high average daily dosing rate, usually between 100 and 1000 gpd/sq. ft.

Hydraulic Detention Time The theoretical time required to displace the contents of a tank or unit at a given discharge rate (volume of tank divided by discharge rate).

Hydraulic Loading The volume of wastewater applied to a unit in a given time.

Industrial Wastewater Wastewater in which wastes from industrial processes predominate.

Influent Wastewater or other liquid flowing *into* a reservoir, basin, treatment process, or treatment plants.

Intermittent Filter A trickling filter which is dosed intermittently rather than continuously.

Kessener Brush A cylindrical metal brush used to maintain circulation and provide oxygen in the activated sludge process.

Kinetic Data Recorded measurements used to determine rates of microorganism growth and substrate removal.

Kraus Process A modification of the activated sludge process in which liquid from anaerobic digesters is added to the aeration basins as a source of additional nutrients.

Log Growth Phase The period of time when the mass of microorganisms is doubling at regular intervas.

Low-Rate Filter A trickling filter designed to be operated with a hydraulic load of 25 to 100 gpd/sq. ft. of filter surface. Also called standard-rate filter.

Mean Cell Residence Time Average period that a cell is held in the activated sludge process; also known as solids retention time.

MechanicalAeration A class of processes by which the surface of an aeration tank is mechanically agitated to cause spray or wave resulting in aeration of the liquid.

Metabolism The life-process in which food is utilized.

Micronutrients Inorganic nutrients required in only trace amounts.

Microorganism Very small organisms that can be seen only through a microscope. Some microorganisms use the wastes in wastewater for food and thus remove or alter much of the undesirable matter.

Mixed Liqour The mixture of activated sludge and wastewater in an aeration tank.

Mixed Liquor Suspended Solids (MLSS) Defined by testing method (see Standard Methods). May be roughly defined as non-filterable solid particles in mixed liquor.

Mixed Liquor Volatile Suspended Solids (MLVSS) Defined by testing method (see Standards Methods). May be roughly defined as that part of the mixed liquor suspended solids that is combustible.

Motile Capable of movement.

Nematode Unsegmented worm.

New Growth Rate The rate of increase in the mass of live microorganisms calculated by subtracting the death rate from the synthesis rate.

Nitrification The biochemcial conversion of unoxidized nitrogen (amonia and organic nitrogen) to oxidized nitrogen (usually nitrate).

Nutrients Elements which are needed to support living cells such as carbon, hydrogen, oxygen, nitrogen, and phosphorus.

Organic Matter High Energy carbon compounds, usually from plant or animal sources, but sometimes synthetic.

Oxidation A chemical reaction, usually involving the addition of oxygen and the release of energy.

Oxygen Uptake Rate The rate at which oxygen is transferred to wastewater under aeration.

Oxygen Utilization The oxygen consumed to support aerobic biological treatment processes.

Parshall Flume A device which measures the critical depth to determine flow.

Peak Load The maximum rate of flow to a wastewater treatment plant.

pH An expression of the intensity of the alkaline or acidic strength of a water.

Photosynthesis The use of sunlight to obtain the energy necessary to synthesize new cell material.

Pin Floc Very fine floc particles with poor settling characteristics.

Plain Sedimentation Sedimentation without the aid of chemicals.

Plug Flow Reactor Idealized continuous flow reactor in which fluid particles are discharged in the same order in which they entered.

Ponding The formation of pools or ponds of wastewater as a result of surface clogging in trickling filters.

Preaeration A preparatory treatment of wastewater consisting of aeration to remove gases, add oxygen, promote flotation of grease, and aid coagulation.

Pretreatment The use of racks, screens, communitors, and grit removal devices to remove metal, rocks, sand, eggshells, and similar materials which may hinder the operation of a treatment plant.

Primary Treatment The first phase of wastewater treatment, consisting of separating the readily settleable or floatable solids by sedimentation and skimming.

Protoplasm The material of a living cell.

Protozoa Animal-like microorganisms.

Psychoda The generic name of filter flies.

Raw Wastewater Wastewater before it receives any treatment.

Reactor Any vessel in which a chemical, biochemical, or physical reaction takes place.

Recirculation The return of a portion of the wastewater which has already passed through a trickling filter for a second passage.

Respiration The process by which a cell takes up oxygen and gives off the carbon dioxide formed in energy-producing reactions.

Rising Sludge A problem in secondary settling tanks generally attributed to denitrification in the sludge blanket.

Rotary Distributor A movable distributor made up of horizontal arms that extend to the edge of the circular filter bed, revolve about a central post, and distribute liquid over the bed through holes or jets in the arms.

Rotifer A small, multi-celled animal that gets its name from the rotating action of rows of cilia near its mouth.

Roughing Filter A trickling filter of relatively coarse material operated at high rate to afford preliminary treatment.

Scum Collector A mechanical device for skimming and removing scum from the surface of a settling tank.

Secondary Treatment Phase of wastewater treatment in which dissolved or suspended material is converted into a form more readily separated from the wastewater.

Sedimentation The process of settling suspended solids by gravity.

Septic A condition produced by growth of anaerobic organisms.

Settleable Matter See Settleable Solids.

Settleable Solids That matter in wastewater which will not stay in suspension during a preselected settling period, either settling to the bottom or floating to the top.

Settled Wastewater Wastewater from which most of the settleable solids have been removed by sedimentation.

Sewage Spent water of a community.

Shock Load The arrival at a plant of a waste which is toxic to organisms in sufficient quantity or strength to cause operating problems. Organic or hydraulic overloads can also cause a shock load.

Side Water Depth (SWD) The depth of water measured along a vertical exterior wall.

Sloughing The dropping or washing off of slime from trickling filter media.

Sludge The solids separated from liquids during processing.

Sludge Age A measure of the length of time a particle of suspended solids has been undergoing aeration.

Sludge Blanket A layer of sludge suspended within an enclosed body of wastewater, such as a settling tank.

Sludge Bulking Poor settling due to low density floc in the activated sludge process.

Sludge Digestion A process by which organic matter in sludge is converted into a more stable form by anaerobic or aerobic organisms.

Sludge Density Index The reciprocal of the sludge volume index (SVI) multiplied by 100 (i.e. 1/SVI × 100).

Sludge Volume Index The ratio of the volume in milliliters of sludge settled from a 1,000-ml sample in 30 min to the concentration of mixed liquor in milligrams per liter multiplied by 1000.

Solids Retention Time (SRT) The average residence time of suspended solids in a biological waste treatment system, equal to the total weight of suspended solids in the system divided by the total weight of suspended solids leaving the system per unit time.

Solids Loading The weight or mass of solids applied to a treatment process per unit time.

Soluble Capable of dissolving readily.

Stabilization Conversion to a form that resists change.

Stage A process which is followed or preceded by a similar process.

Standard-Rate Filter See Low-Rate Filter.

Step Aeration Same as step feed.

Step Feed Adding wastewater at points along the length of an aeration basin rather than just at the head end.

Supernatant Liquid removed from settled sludge.

Substrate The substance being used by microorganisms in suspension.

Suspended Matter See Suspended Solids.

Suspended Solids (SS) Defined by testing method (see Standard Methods), but may be roughly defined as all non-dissolved solids that take a certain minimum time to settle in still water.

Synthesis The creation of new material from elementary building blocks.

Tapered Aeration An aeration method whereby the quantity of air added varies along the aeration basin with a maximum at the head end and a minimum at the outlet end.

Toxicity The ability of a waste to poison organisms.

Trickling Filter A biological treatment process in which the wastewater trickles through a bed of slime-covered media and is treated by the action of the microorganisms in the slime layer.

Trickling Filter Media The solid material in a trickling filter which provides a surface for a biological film of microorganisms. Crushed stone is the most commonly used media, but plastics are gaining popularity.

Turbidity Cloudiness of wastewater due to suspended solids.

Virus The smallest form capable of producing diseases in man or other higher organisms.

Volatile Matter See Volatile Solids.

Volatile Solids Defined by testing method (see Standard Method), but may be roughly defined as combustible solids.

Wastewater The used water and solids that flow to a treatment plant.

Zooglea A jelly-like coating developed by bacteria.

Zooleal Matrix The floc or slime formed by zoogleal bacteria.

(Definitions principally from *Glossary of Water and Wastewater Engineering*, APHA, ASCE, AWWA, and WPCF (1969); "Operation of Wastewater Treatment Plants," EPA (1970); *Wastewater Engineering*, Metcalf & Eddy (1972); *Biology of Microorganisms*, Brock (1974).)

METRIC SYSTEM REFERENCE

THERE ARE THREE BASIC METRIC UNITS AND THEY ARE: METERS WHICH MEASURE LENGTH; GRAMS WHICH MEASURE WEIGHT (MASS); AND LITERS WHICH MEASURE VOLUME OR CAPACITY. THE METRIC SYSTEM IS BASED ON THE NUMBER 10 WITH PREFIXES TO SPECIFY THE MULTIPLE OR FRACTION OF THE BASIC UNIT. THE PREFIXES COMMONLY USED ARE:

Prefix	Multiplier	Prefix	Multiplier
mega, M	1,000,000	deci, d	0.1
kilo, k	1,000	centi, c	0.01
hecto, h	100	milli, m	0.001
deca, da	10	micro, μ	0.000001

CONVERSION FACTORS

ENGLISH UNIT	SYMBOL	ENGLISH TO METRIC MULTIPLY BY	METRIC TO ENGLISH MULTIPLY BY	METRIC UNITS	SYMBOL
acre	ac	4046.9	0.00024711	square meters	m^2
acre-feet	acre-ft	1233.5	0.0008107	cubic meters	m^3
cubic feet	cu ft	0.02832	35.315	cubic meters	m^3
cubic feet	cu ft	28.32	0.035315	liters	l
cubic feet/gallon	cu ft/gal	7.482	0.0001336	liters/cubic meter	l/m^3
cubic feet/pound	cu ft/lb	0.06243	16.02	cubic meters/kilogram	m^3/kg
cubic yard	cu yd	0.7646	1.308	cubic meters	m^3
feet	ft	0.3048	3.281	meters	m
gallon	gal	3.785	0.2642	liters	l
gallon	gal	0.003785	264.2	cubic meters	m^3
gallon per day/sq foot	gpd/sq ft	0.04074	24.55	cubic meter/sq meter per day	$m^3/m^2 \cdot d$
gallon per minute	gpm	0.06308	15.85	liters per second	l/s
gallon per minute/sq foot	gpm/sq ft	0.67902	1.473	liters/sq meter per second	$l/m^2 \cdot s$
pound	lb	0.4536	2.205	kilograms	kg
pounds/1,000 cubic feet	lb/1,000 sq ft	16.02	0.06243	grams/cubic meter	g/m^3
pound/day/cubic foot	lb/day/cu ft	16.02	0.06243	kilograms/cu meter per day	$kg/m^3 \cdot d$
pound/million gallon	lb/mil gal	0.1198	8.344	grams/cubic meter	g/m^3
million gallon	mil gal	3785.0	0.0002642	cubic meters	m^3
million gallons/day	mgd	3785.0	0.0002642	cubic meters/day	m^3/day
million gallons/day	mgd	0.0438	22.83	cubic meters/second	m^3/s
pounds/cubic foot	pcf	16.02	0.06243	kilograms/cubic meter	kg/m3
pounds/square foot	psf	4.882	0.2048	kilograms/square meter	kg/m2
pounds/square inch	psi	0.0703	14.22	kilograms force/sq centimeter	$kg\ f/cm^2$
square feet	sq ft	0.0929	10.76	square meter	m^2
square inch	sq in	645.2	0.00155	square millimeter	mm^2

RECOMMENDED WASTEWATER UNITS OF EXPRESSION

DESCRIPTION	ENGLISH UNIT	METRIC UNIT
Wastewater Flow	gallons per day, cubic feet per second million gallons per day gallons per minute	cubic meters per second cubic meter per day liters per second
Hydraulic Loading	gallons per day per square foot of surface area	cubic meters per day per square meter of surface area
Organic Loading	pounds of BOD_5 (or COD) applied per day per thousand cubic feet of volume pounds of BOD_5 (or COD) applied per day per pound of mixed liquor volatile suspended solids (MLVSS)under aeration	kilograms of BOD_5 (or COD) applied per day per cubic meter of volume kilograms of BOD_5 (or COD) applied per day per kilogram MLVSS under aeration
Aeration Period	hours of detention in aeration tank excluding return sludge (RAS) flows	same as English units
Air Requirement	cubic feet of air per pound of BOD_5 (or COD) removed cubic feet of air per gallon of wastewater treated	cubic meters of air per kilogram of BOD_5 (or COD) removed Liters of air per cubic meter of wastewater treated
Air Flow	cubic feet per minute	cubic meters per second or liters per second
Volume	million gallons, cubic feet, or gallons	cubic meters or liters

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